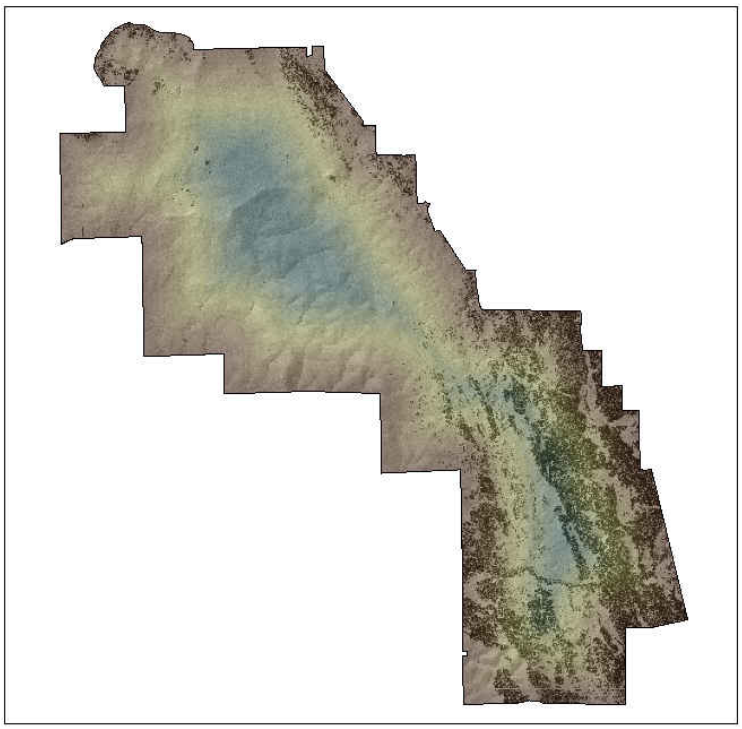
Environmental Security Technology Certification Program (ESTCP)

Final Report Addendum for Former Camp Beale Demonstration Site

Project Number UX-0534

High Density Lidar and Orthophotography in UXO Wide Area Assessment Phase 2



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ABBREVIATIONS AND ACRONYMS

AOI	Area of Interest
ASR	Archival Search Report
BLM	US Bureau of Land Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	Conceptual Site Model
DBT	Demolition Bombing Target
DEM	Digital Elevation Model
DoD	Department of Defense
EM	Electromagnetic
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
GIS	Geographical Information System
GPS	Global Positioning System
HE	High Explosive
IMU	Inertial Measurement Unit
lidar	Light Detection and Ranging
MEC	Munitions and Explosives of Concern
MM	Munitions Management
MRA	Munitions Response Area
MRS	Munitions Response Site
NDIA	New Demolitions Impact Area
OB/OD	Open Burn/Open Detonation
PBR	Precision Bombing Range
QA	Quality Assurance
QC	Quality Control
SAR	Synthetic Aperture Radar
SDS	Spatial Data Standard
SORT	Simulated Oil Refinery Target
TIN	Triangulated Irregular Network
TRSI	Terra Remote Sensing, Inc.
UXO	Unexploded Ordnance
WAA	Wide Area Assessment

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Grateful acknowledgement is also made to our demonstration partner Terra Remote Sensing, Inc. of Sydney, British Columbia, who performed lidar and orthophoto data acquisition and contributed significantly to development of data analysis and QA/QC methods.

EXECUTIVE SUMMARY

Since 2005, the Environmental Security Technology Certification Program (ESTCP) has conducted a pilot program to test the effectiveness of a multi-technology approach to UXO/MEC Wide Area Assessment (WAA). The first phase of this program was carried out at three desert sites containing little or no vegetation and few non-military land uses; results from this first phase were very positive. Subsequently, a second phase of the pilot program was added, including two new sites: the Former Camp Beale site near Marysville, California, and the Toussaint River site near Lake Erie. The Former Camp Beale site is located approximately 20 miles from Marysville, California, and covers an area of approximately 18,263 acres (2,391 hectares).

URS Corporation and Terra Remote Sensing, Inc. were awarded ESTCP funds to demonstrate the utility of high-density lidar and orthophotography as one component of the WAA Pilot Program. The URS team collected lidar and orthophotography at two sites during the first phase of the program, and at the Former Camp Beale demonstration site which is the subject of this report addendum. Data for the Former Camp Beale site was collected over a two-week period in July, 2006.

The objectives for the Former Camp Beale demonstration site were similar to those for the previous demonstration sites: to examine the ability of lidar and high-resolution orthophotos to identify and delineate MRS and MEC-related ground features, to verify or correct data in the existing CSM and ASR, and to contribute data that could be used to focus and prioritize the use of more expensive low-altitude or ground-based technologies.

These objectives were met. Lidar and orthophoto data were successfully used to identify MRS and munitions-related features, and to verify and correct the initial CSM. Information from the demonstration was successfully used by ESTCP to plan subsequent phases of site investigation including the use of helicopter- and ground-based magnetometry and site reconnaissance. The demonstration, including the validation activities conducted following data acquisitions, provided important insights regarding the appropriate uses and confidence levels for both technologies. All positional accuracy specifications were met.

The Former Camp Beale site is more complex than the previous WAA Pilot Program sites. The area includes a much wider variety of land uses, including residential, ranching and mining, as well as a wider variety of munitions-related activities. For this reason, a much wider variety of potential features appears in the lidar and orthophoto data. Of these, some were clearly MEC-related, including two large crater fields, one bull's eye aiming target, and two potential firing ranges. Significantly, the aiming target was outside (though near) any of the mapped target areas in the initial CSM. Many ground features were clearly not ordnance-related, including small water impoundments and disturbed areas around houses.

Of the ground features detected, many more were ambiguous than at the previous demonstration sites. Lidar and orthophotos did not, by themselves, provide sufficient data to determine the origin of these features. A follow-up site visit was performed in February, 2007 to examine some of the ambiguous features. During the site visit, 134 features were visited over three days; the features were photographed and examined with a Schondstedt hand-held magnetometer. Of these,16 (12%), were estimated to be munitions related. These figures may not be representative of the entire site, as right of entry could not be maintained for the areas of the site containing the bombing targets. Some characteristics were observed in the field that could then be used in subsequent re-analysis of the lidar and orthophoto data for the features that were not visited; these included the shape, size location in relation to other potential features. Other characteristics were observable in the field that could not easily be used in subsequent re-analysis, in particular old mine shafts were clearly distinguishable as non-MEC in the field, but their shapes were not easily distinguished from potential craters in the lidar data.

Vegetation conditions at the Former Camp Beale site are more varied than at the earlier demonstration sites, including areas of thick grass, brush and open deciduous forest. The varied vegetation conditions allowed for the preliminary examination of the effects of vegetation on the effectiveness of lidar and orthophotography. In general, the high lidar data densities acquired provided detailed surface models in the relatively open forest areas, but did not penetrate the thick brush along stream channels.

As with the two sites previous investigated by URS, lidar and orthophotography proved to be cost-effective and reliable means to characterize the site, validate and correct the initial CSM, and provide data to focus the subsequent application of subsequent methods of investigation.

These technologies were not able to characterize every potential ground feature, but were useful for identifying features for follow-up field work.

1.0 INTRODUCTION

1.1 BACKGROUND

Many millions of acres of Department of Defense (DoD) lands are potentially contaminated with military munitions or their components. On the majority of these sites, munitions are concentrated in specific ranges and training areas, while the remainder of the site is ordnance-free. Contaminated sites have traditionally been very expensive to investigate and remediate because of the nature of the contamination and the relatively few innovative approaches available to date.

The current demonstration was conducted as part of the second phase of the Environmental Security Technology Certification Program (ESTCP) Wide Area Assessment (WAA) Pilot Program. Since 2005, this program has explored the use of an integrated suite of airborne and ground-based technologies as a means to streamline the WAA process, resulting in both cost savings and increased confidence in results. Light Detection and Ranging (lidar) and orthophotography, the subjects of this demonstration, were used in conjunction with synthetic aperture radar (SAR), hyperspectral sensing, helicopter-based magnetometry, and towed-array magnetometry and electromagnetic induction (EMI), along with statistical modeling, in an integrated Geographical Information System (GIS)-based analytical environment.

The first phase of the WAA Pilot Program examined three sites, the Pueblo PBR site near La Junta Colorado, the Kirtland PBR site near Albuquerque, New Mexico, and the Victorville DBT "Y" site near Victorville, California. All three sites were desert bombing ranges with little vegetation and few non-military land uses. The results of the first phase were positive. The combination of technologies employed were successfully used to locate Munitions Response Sites (MRS) and munitions-related features, to correct the initial Conceptual Site Model (CSM), and to support regulatory decisions about the need for further investigation or site remediation. The combination of technologies employed in the Pilot Program was cost-effective and provided a high degree of cross-validation.

As a result, a second phase was added to the program, including two additional sites. The first site, Former Camp Beale, is located approximately 10 miles from Marysville, California, just to the east of Beale Air Force Base. The site covers approximately 18,263 acres (2,391 hectares). The site is more complex than the Phase 1 sites, with more vegetation types, more complex topography, and a wider variety of land uses. The second site was the Toussaint River site near Lake Erie, which was primarily an underwater detection site.

This report addendum discusses the results of lidar and orthophoto data collection and analysis at the Former Camp Beale demonstration site. Overall results from the WAA Pilot Program, and

the relationship of these two technologies to the entire suite of technologies tested, are discussed in the final report for the WAA Pilot Program as a whole.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of the overall WAA Pilot Program demonstration are unchanged from those referenced in the Kirtland AFB Demonstration Plan. The objectives for the current demonstration site were similar to those for the previous demonstration sites: to examine the ability of lidar and high-resolution orthophotos to identify and delineate MRS and MEC-related ground features, to verify or correct data in the existing CSM and ASR, and to contribute data that could be used to focus and prioritize the use of more expensive low-altitude or ground-based technologies.

1.3 REGULATORY DRIVERS

MEC remediation is generally conducted under authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). With many millions of acres of land potentially contaminated with MEC, estimates of the cost of elimination of environmental liability under this statute at known and former DoD sites range as high as several hundred billion dollars. These potentially high costs have led to interest in the development of innovative investigative or screening methods, in order to reduce the costs of conducting WAA and associated remediation activities.

1.4 STAKEHOLDER/END-USER ISSUES

The results from the Former Camp Beale site, like those from the previous sites, showed that both lidar and orthophotos can contribute to the WAA process through cost-effective delineation of MRS- and MEC-related features. The demonstration results support the conclusion from the first phase sites that lidar and orthophotos are most appropriately used during the early phases of the WAA process, in order to focus and prioritize the subsequent application of more expensive low-altitude and ground-based technologies.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

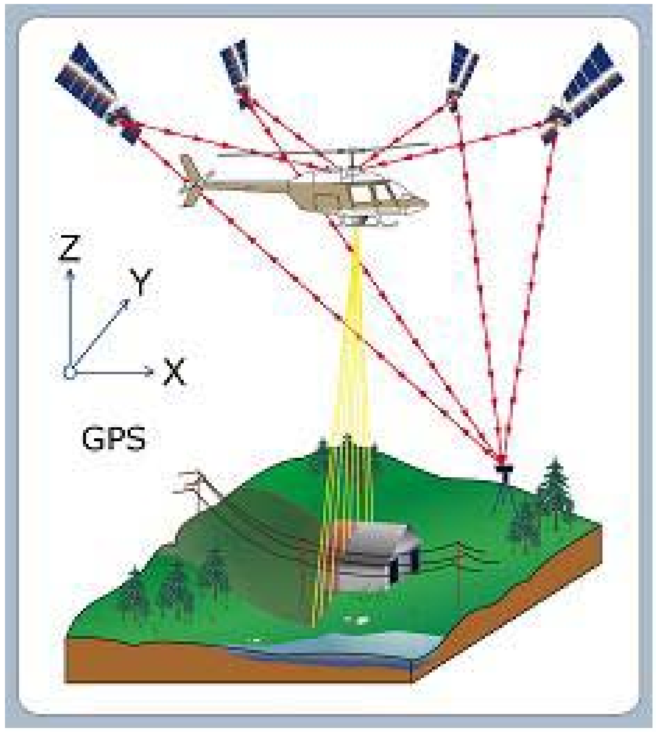
2.1.1 Technology Background

Lidar is a well-established airborne technology for modeling ground surfaces. Topographic lidar was first developed in the late 1960s and early 1970s, and has been used for terrain profiling since the mid-1980s. Lidar has been in wide commercial use since around 1993, and the accuracies and limitations of lidar for surface modeling are well documented.

Lidar utilizes the time of return for a laser pulse to be reflected back to the sensor to measure the elevation of the point of reflection. Use of Global Positioning System (GPS) and Inertial Measurement Unit (IMU) technology to locate the sensor precisely in the air allows for the accurate calculation of the point of reflection of the laser signal from the ground, buildings or vegetation. Multiple returns from a single laser pulse can be detected, increasing the chance of sampling the ground surface through gaps in vegetation. Once elevation data is collected in the form of lidar points, surface models are created and analyzed. The surface modeling process is typically conducted using standard GIS software and methods, and much of the process can be successfully automated. Lidar vendors typically guarantee a vertical accuracy of 0.15 m and a horizontal accuracy of 0.3–0.75 m.

Figure 2-1
Helicopter-mounted Lidar and Orthophoto Sensor Equipment

Figure 2-2
Lidar System Operations



The development of higher-speed (50–150 kHz) laser scanners beginning around 2002 has significantly improved the ability of lidar to locate small features. Currently, high-speed lidar systems are being used to characterize objects in the sub-meter range, such as power line insulators. The accuracy and data density of current lidar systems suggest that the technology could be used to detect ground features indicative of ordnance use, including targets and craters, and that the presence of these features could in turn be used to develop more accurate locations of MEC.

Digital orthophotography has been commercially available since the early 1980s, with steady improvement in the resolution (i.e., pixel size) and precision (i.e., pixel placement) of the images as the technology of digital cameras, GPS, and IMU systems has advanced. Since the mid 1990s, image size has advanced from 1,500 pixels across an image to 4,500 pixels. This has allowed for increased flying heights and a reduced number of images for a given area, with consequent cost savings. Commensurate with this improvement has been a twofold increase in the accuracy of the IMU, allowing for accurate positioning of image pixels at a higher flying height.

Airborne digital cameras have been successfully integrated with lidar sensors. Cameras with an image density of roughly 4,000 x 4,000 pixels are generally favored, because the width of the images collected is very similar to that of the typical lidar point swath. Once collected, individual digital images are tiled together and color balanced, and the resulting composite image is orthorectified using the lidar data. Orthorectification allows for the accurate location of each photo pixel, eliminating distortion caused by camera angle and topography. Vendors generally guarantee a horizontal accuracy of 3 pixel widths compared to ground control for orthophotography.

Digital images are collected concurrently with lidar and, because the two sensors use the same GPS and IMU, the two data sets can be very accurately integrated. Vendors generally guarantee spatial integration of orthophotos and lidar within 2 pixel widths. Final orthophoto pixel size depends on the flight altitude and the camera specifications; helicopter-based cameras flying at altitudes of 400–450 meters are capable of pixel sizes of approximately 10 cm. Smaller pixel sizes than this are generally impractical due to the low flight elevations and slow flight speeds required to collect properly overlapping images, and the very large numbers of images that would need to be combined into a mosaic.

The ability to produce spatially accurate orthophotos with relatively small pixel sizes suggests that this technology could be used to identify ordnance-related features, and to cross-validate technologies such as lidar.

2.2 PREVIOUS TESTING OF THE TECHNOLOGY

As part of the first phase of the ESTCP WAA Pilot Program, lidar and orthophotos were tested at three demonstration sites: Former Kirtland AFB PBR near Albuquerque, NM, Victorville DBR "Y" site near Victorville, CA and Pueblo PBR near Pueblo, CO. Lidar and orthophotos were successfully used to detect large bombing targets such as bull's-eye rings and simulated ship targets, despite the fact that the berms making up these targets were weathered and frequently less than 10 cm tall, and were not visible to ground crews on the site. Individual munitions-related features were also detected using lidar, including potential craters down to approximately 1 m in diameter.

2.3 FACTORS AFFECTING COST AND PERFORMANCE

The following factors were found to affect either cost or performance at both the first phase sites and the Former Camp Beale site. These factors are consistent with industry standard guidance on the use of lidar and orthophotos in a variety of applications.

Table 2-1
Cost and Performance Factors

Item	Cost and Performance Factors
Lidar data density	Higher lidar data density performs better but is generally more expensive, due to the need to acquire and process additional flight lines.
Orthophoto data density	Orthophotos with smaller pixels are more effective but more expensive, because of the additional flight lines required and the larger number of individual digital images which must be processed and mosaiced.
Accuracy and precision requirements	Accuracy and precision are largely determined by the equipment used and the care of the operators. Projects with extremely high accuracy requirements, such as creation of contour lines under 1-foot intervals, can only be accomplished by vendors with newer equipment.
Site location and logistics	Sites with longer flying times to an airport will be more expensive, as they will require either longer flight times or placement of fuel on the test site.
Verification of accuracy and precision	Verification of accuracy and precision is accomplished through placement survey control and comparison of lidar and orthophoto data to such control. Projects with higher verification requirements will be more costly, although this factor is small compared to other factors.
Site size	Larger sites can achieve substantial cost savings through amortization of fixed cost, such as mobilization and project planning, as well as through increased efficiency in data acquisition and processing.
Vegetation conditions	Vegetation impacts the ability of both lidar and orthophotos to view or model the ground surface. More densely vegetated sites will have higher costs due to the requirement for additional lidar passes to achieve sufficient point density at the ground surface.
Permitting and site access	Some DoD sites contain high-security areas, which can raise costs for pre-flight planning and data collection. These costs result from restrictions on site access, time to acquire needed clearances, and longer flight times to avoid restricted areas. Sites with environmental constraints do not normally impose higher costs for lidar and orthophotography, due to the airborne nature of the technologies. However, the presence of sensitive species may affect pre-flight planning and scheduling (and thus costs) for projects which require landing to re-fuel on the site.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The use of lidar and orthophotos offers several advantages compared to the traditional approaches to MRS investigation. As with the factors affecting the cost and performance, these factors were found to apply to both the first phase sites and the Former Camp Beale site.

Table 2-2
Technology Advantages and Limitations

Item	Advantages
Rate of coverage	In an operational setting, data collection rates of 5,000 acres per day or higher can be expected for lidar and orthophotos. This compares favorably to maximum collection rates of around 500 acres per day for helicopter-based magnetometry, and 20 acres per day for towed-array magnetometry.
Ability to delineate MRS and MEC-related features	Lidar and orthophotography can, under some circumstances, successfully reveal MRS and MEC-related surface features even many years after their last use.
Enhanced planning and risk assessment	Because they can cover entire sites relatively quickly and at lower cost, these technologies can be used to locate and prioritize appropriate areas for use of more costly low-altitude and ground-based technologies.
Other benefits	Both technologies provide highly detailed topographic data that can be integrated into a facility's CADD or GIS system and used in subsequent phases of site investigation, site remediation, and range management

Lidar and orthophotos have the following limitations compared to other existing technologies:

Item	Disadvantages
MEC detection	Neither lidar nor orthophotography can directly detect shell casings or other MEC components such as scrap. Consequently, further investigation with magnetometers or electromagnetic induction (EMI) sensors is required.
Elevation data	Orthophotos do not contain elevation information. In practice, it is sometimes difficult to distinguish small surface depressions from small mounds or shadows using orthophotos alone.
Vegetation effects	Since both lidar and orthophotos are light-based technologies, neither will penetrate vegetation. Orthophotos do not "look through" vegetation, and lidar point densities will be lower in vegetated areas. However, lidar is frequently successful in penetrating small openings between and within vegetation, and this success has increased with the speed of lidar sensors and the development of the ability to measure multiple returns.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The primary performance objectives for these technologies were similar to those for the first phase sites, as applied to the more complex environment of the Former Camp Beale site.

- Clarify whether and to what extent lidar and orthophotos can delineate MRS boundaries and MEC-related features, and contribute to the focusing and prioritization of subsequent low-altitude and ground-based work.

- Reveal relationships between the density of lidar and orthophoto data, their levels of cost, and their ability to accurately locate MRS boundaries and MEC-related ground features.

- Clarify whether and to what extent lidar and orthophotos can verify, reveal errors in, or improve the accuracy of the initial CSM.

- Contribute data and analysis to the overall combination of technologies used in the WAA Pilot Program, in a manner that is timely to the application of the other technologies demonstrated, in formats useable by other demonstrators, and with sufficient positional accuracy compared to project control points to allow meaningful coordination and comparison.

Specific performance criteria and performance metrics related to each of these objectives are established in the Technology Demonstration Plan for this site.

3.2 SELECTION OF TEST SITE

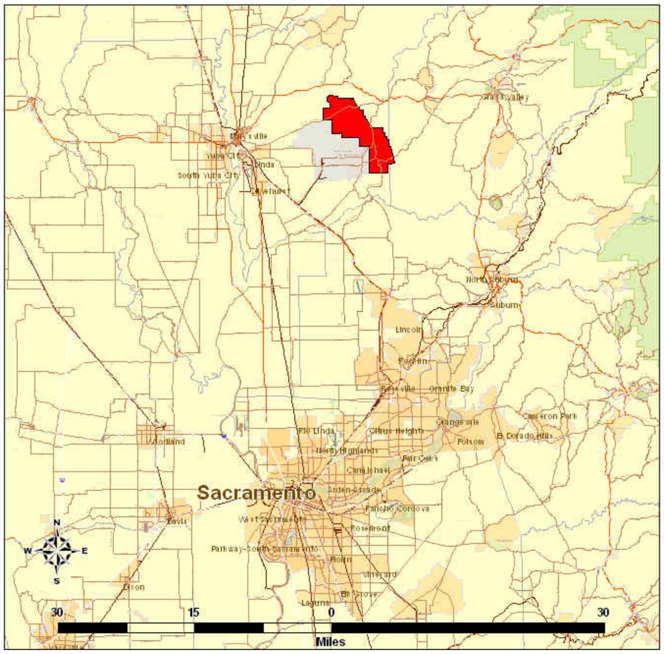
The demonstration site was chosen by the ESTCP Program Office. Details of the site selection process can be found in the final report for the second phase of the WAA Pilot Program.

3.3 TEST SITE HISTORY, CHARACTERISTICS AND PRESENT OPERATIONS

The Former Camp Beale site consists of 87,672 acres approximately 20 miles east of Marysville, California, between Yuba and Nevada counties. The site is located immediately to the east of Beale Air Force Base. The demonstration site was used by the DoD for ground ranges, moving target ranges and bombing ranges between 1943 and 1959. Historic photographs revealed extensive ground disturbances, expected to have been created during previous MM-related activities. Other areas from the historical photographs were noted as disturbed, either by ground scarring, visible craters, or other activities. According to the CSM, cleanup activities were conducted in 1947, and 1958 – 1959.

The Former Camp Beale site was excessed and sold between 1959 and 1964 and now contains both private land and state land located within the Spenceville Wildlife Reserve.

Figure 3-1
Former Camp Beale Demonstration Site Location



3.4 PRE-DEMONSTRATION TESTING AND ANALYSIS

Pre-demonstration activities included scheduling, flight line planning, planning for placement of project controls and securing appropriate site access. Scheduling included reservation of a local helicopter and pilot, determining the most appropriate local airport from which to base operations, and arranging shipping for the sensor equipment and accommodations for the field crew. Helicopter use was scheduled to include an extra day for re-acquisition of any problem areas or missed areas.

Flight lines were planned to ensure complete site coverage, minimize the number of turns, and achieve planned overlap. Digital imagery was planned for acquisition at periods of low sun angle. Previous testing had shown that the shadows created by low sun angle were useful in detecting shallow features. Flight line planning included coordination with Beale Air Force Base to secure permission to turn in the base air space.

Planned controls included 18 surveyed control points, 10 test craters and 4 vertical control structures. The demonstration site includes a considerable amount of private land currently used for ranching and as rural residences, and right of entry could not be secured for placement of

control points on some private land areas. In these parts of the project area survey control points were planned for placement in the right-of-way of public roads. Test craters and vertical control structures were planned for placement on public land and private land with right of entry.

3.5 TESTING AND EVALUATION PLAN AND PROCEDURES

3.5.1 Demonstration Set-Up and Start-Up

At the site, the lidar and orthophoto sensor system was installed into a helicopter owned by a local vendor. Use of local helicopters and pilots is a common industry practice which allows the lidar vendor to ship only the sensor package rather than the aircraft. The use of local helicopter vendors also allows for the use of local pilots who have better knowledge of local weather patterns and flight clearance requirements.

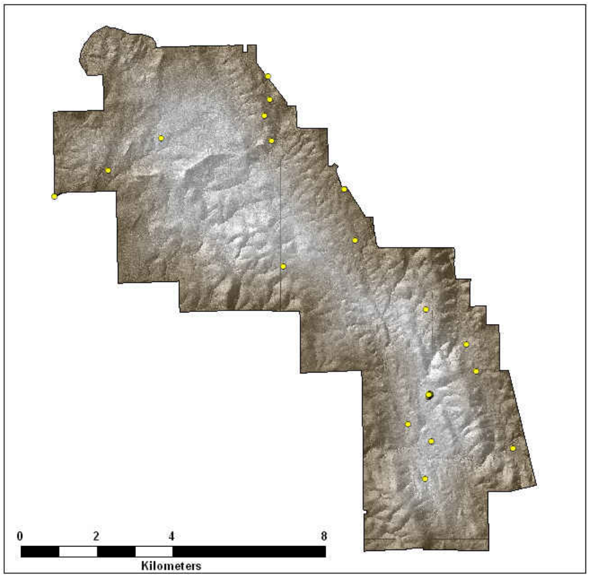
Figure 3-2

Equipment installation

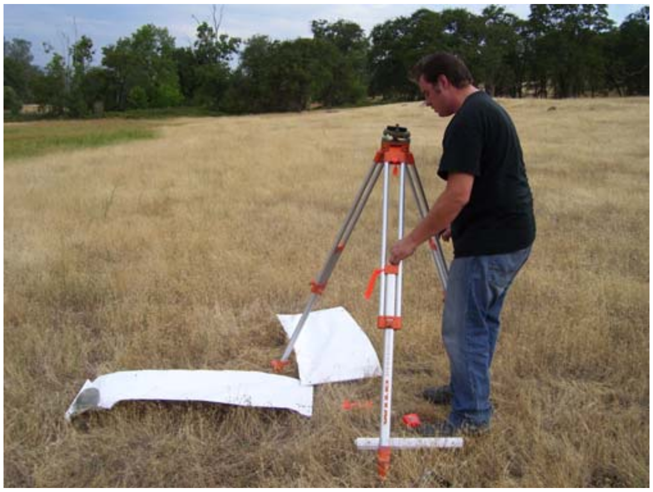
Sensor pod mounted below helicopter, control console visible through window.

Concurrently with installation of the sensor equipment, the field crew installed control points, test craters, and vertical control structures. Examples are shown in the following images.

Figure 3-3



Control point locations, Former Camp Beale



Example Camp Beale control point

Figure 3-4

Control point within road right-of-way.

Control point within road right-of-way.

Figure 3-4

Vertical control structure

Existing bunker used as vertical control structure

Figure 3-5

1.5 m test crater.

0.3 m test crater.

3.5.2 Period of Operation and Area Characterized

On July 27, 2006, a calibration flight at 450 meters was conducted to establish appropriate pitch, yaw, and roll correction factors. A laser pulse rate of 75 kHz was selected based on performance at a variety of speeds tested and the contract specifications.

Data collection flights were begun once mobilization, sensor installation, and calibration flights were complete. Data collection flights were conducted from the airport at Yuba, California. Data collection periods were as follows:

Table 3-1
Data Collection Periods

Activity	Period
Preflight planning	June 1 – July 20 2006
Mobilization	July 20, 2006
Calibration flight	July 27, 2006
Data collection	July 22-26, 2006
Verification of radar corrections	July 27-31, 2006
Demobilization	July 31, 2006

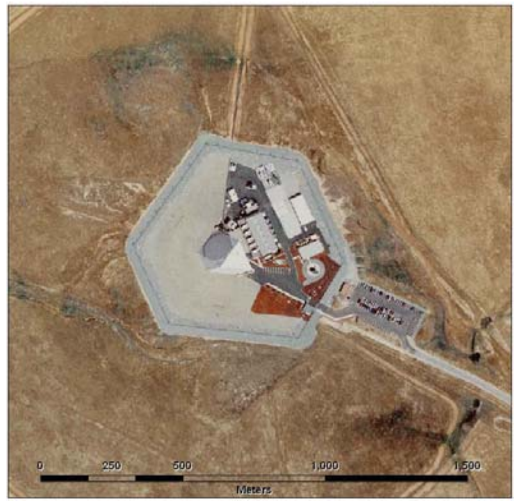
3.5.3 Site Conditions Affecting Data Collection

Data collection was affected by two site conditions that should be considered in planning for future use of these technologies. First, data collection took place during mid-summer, and ambient air temperatures during data collection often exceeded 110^{o} F. These temperatures led to difficulties with helicopter operation, including inability to reach planned altitudes and speeds. High temperatures also affected the sensor equipment directly. As a result, data collection could only take place in the early morning hours. As a result, the day reserved for re-acquisition of any missed or problem areas was used to complete data collection.

Second, Beale AFB is the site of one of three installations that are part of the Phased Array Warning System (PAWS) radar system, designed to detect and track sea-launched ballistic missiles. The high-intensity radar signals from this installation disrupted the GPS time signal used by the lidar and orthophoto sensors, rendering the data unusable. The effect was noted within several kilometers of the radar station and at altitudes up to approximately 500 m. The problem was noted during the daily QA/QC checks on the first day of data collection. A sample of the data was sent to the TRSI office in Sidney, BC, and a solution was developed to re-insert the correct GPS times. The field crew stayed on the site for an additional 5 days while this solution was developed and tested.

Figure 3-6

Temperature during data collection



PAWS radar station, Beale AFB

3.5.4 Demobilization

Demobilization of the lidar and orthophoto equipment consisted of dismounting the sensor system from the helicopter, packing and shipping. Demobilization required approximately 4 hours.

3.6 SELECTION OF ANALYTICAL/TESTING METHODS

Analysis of lidar data is performed in two steps: conversion of sensor output to spatially correct lidar points, and then conversion of these points to useable GIS products such as surface models or contour lines. Processing of the Former Camp Beale lidar data into point files was accomplished using a suite of software including TerraSolid and custom algorithms written in this software by TRSI. TerraSolid is an industry standard software package for processing lidar data.

Creation of GIS products and analysis were accomplished using ESRI's ArcGIS software suite. ArcGIS was used because it is the most widely used GIS package by US government agencies and private contractors. As such, it is appropriate to develop analysis methods and resulting products that can be duplicated by typical federal facilities staff.

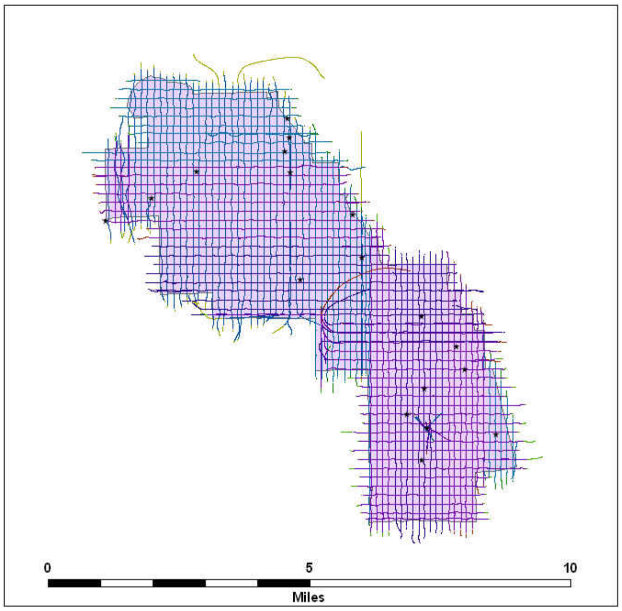
Analysis of orthophoto data was also performed in two steps: creation of orthorectified images from the large number of individual digital images collected followed by visual examination of the image to locate potential MRS and munitions-related features. Processing of the digital imagery to create the orthophoto mosaic was accomplished using software from TerraSolid and PCI. This software is also the industry standard.

3.7 RESULTS

3.7.1 Data Collection

Data collection flights took place on July 22 through 26, 2006 with a total of 120 flight lines accomplished. Lidar data was collected at altitudes of 300 and 450 meters. Orthophoto data was collected concurrently with lidar during the 450 meter flight in order to produce images with a 10 cm pixel size. Complete coverage was obtained for each flight, and flight line overlap was within specifications.

Figure 3-7



Former Camp Beale achieved flight lines

3.7.2 Safety Issues

No special safety issues were encountered during data collection.

3.7.3 Data Processing Steps

Processing of the sensor output to create lidar points was performed by TRSI. Following return of the data to the office, calibration factors determined in the field were checked, fine-tuned, and applied to laser range, GPS, and IMU data to produce x,y,z values for each point. Lidar points were then transformed into the delivery datum and projection, and coded to indicate returns from ground vs. non-ground surfaces. Additional fields for each point included the intensity value, gps date, and flight line number. Lidar points were exported as text files for delivery to URS. Lidar data from each lidar flight was processed and delivered separately in order to allow for

separate analysis of data from each flight altitude. Lidar data was delivered in 345 blocks (for each flight), each covering 1/4 square kilometer, in order to keep file sizes manageable. Even with this size limitation, each of the separate lidar data files contained up to 6.5 million individual lidar points.

Digital image processing was done by TRSI. The procedure included mosaicing of the individual digital images collected during flight, transformation of the consolidated image to the delivery datum and projection, orthorectification using the lidar data, color balancing, and trimming to the delivery tiles. For the Former Camp Beale site, orthophotos were created in blocks of 2.675 square kilometers, in order to keep file sizes manageable. Even with this size limitation, the 19 individual orthophoto blocks were approximately 2 GB each.

Figure 3-8

Orthophoto data blocks.

Conversion of the random lidar point data to GIS products was conducted by URS, using the following steps:

- The lidar points were converted to ArcInfo point shape file format, with the horizontal locations determined by the northing and easting values in the lidar point file, and the elevation value, intensity value, and the code for ground or non-ground return retained as attributes.

- Point shape files were converted to Triangulated Irregular Network (TIN) files. A TIN is an elevation-based surface model where each point forms a vertex in a network of linked triangles. TINs were created separately from the lidar points coded as ground returns and from the entire lidar point set, using ArcInfo's TIN creation functions. TINs were created for each lidar flight.

- Digital elevation models (DEMs) were created from the TINs. A DEM is a regularly spaced, gridded array of elevation values. DEMs were created using the each of the TIN files as inputs. DEMs were created in the ArcInfo GRID file format, which allows for additional analysis that cannot be performed directly on the TIN file. All DEMs were created using 0.3 m (1 ft) grid cell sizes. This value was chosen as the smallest cell size that would be supported by the lidar data densities acquired.

Automation of GIS processing and analysis was accomplished for many of the process steps.

Once the initial GIS products were created, the lidar data were examined to detect missing data, spatial discrepancies, or artifacts in the surface that would indicate improper calibration or other problems. Further data quality review, including review for spatial accuracy, was performed based on the parameters given in Appendix C of the Technology Demonstration Plan. All data met data quality specifications.

Following creation of initial GIS products and initial QA/QC review, hillshades were created for each of the DEMs. Hillshades are three-dimensional depictions of the surface with shadows formed by a simulated light source placed above the surface at an altitude and azimuth chosen by the operator. The default settings for hillshades in ArcGIS Spatial Analyst were used, and then varied as needed during the analysis. Hillshades were saved in ArcInfo GRID format.

Once the initial data processing steps were completed, the lidar and orthophoto data were examined using the following steps:

- Each lidar hillshade and orthophoto data set was visually inspected for potential MRS.

- Potential MRS were identified and drawn as ArcInfo point or polygon shape files for each data set.

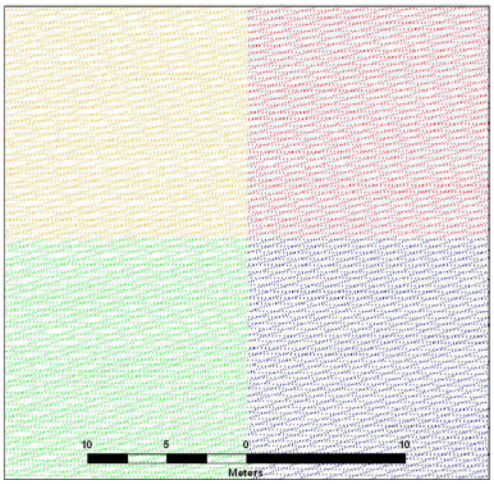
- Each data set was visually inspected for potential munitions-related features. Potential features were drawn as ArcInfo point shape files for each data set.

3.7.4 Processing Lidar Points to Create Seamless Surface Models.

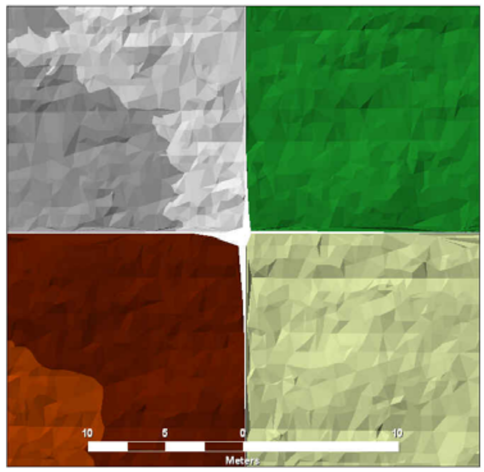
The Former Camp Beale lidar data offered an opportunity to test two different data specifications and their effects on creation of surface models. For the 300 m lidar flight, data was delivered in non-overlapping data blocks, while for the 450 m lidar flight, the lidar data blocks were overlapped by 10 m. This test is relevant because, while lidar vendors can produce overlapping point blocks without extra effort, there is currently no industry standard as to whether point blocks should or should not overlap.

In practice, this specification had a significant effect on the creation of surface models. Non-overlapping point blocks yielded "lines" or areas of no data between the blocks, from approximately 1 foot (0.3 m) in width to 2 or 3 meters at the corners. These gaps result from the operation of the sequential processing steps used to create surface models, each of which increased the width of the no-data area. The process is shown in the following images.

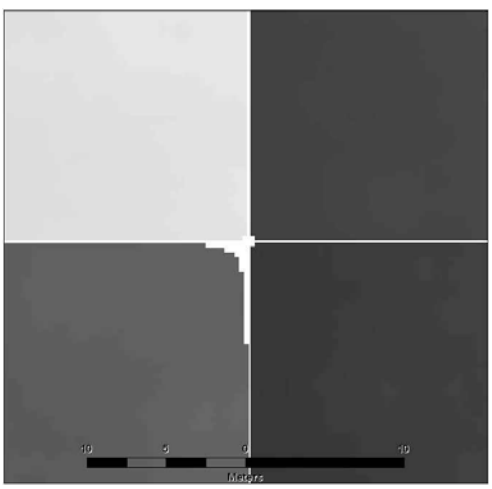
Figure 3-9
Surface Model Gaps between Lidar Blocks



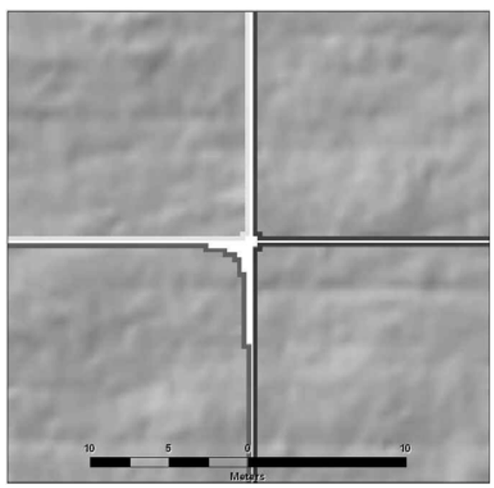
Lidar points, non-overlapping point blocks.



Step 1: TINs created from non-overlapping point blocks. Gaps begin to appear.



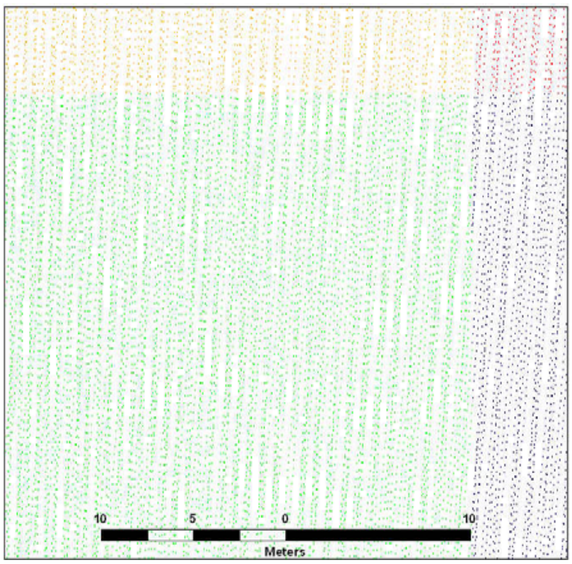
Step 2: Digitial Elevation Models (DEMs) created from TINs. Gaps are slightly larger.



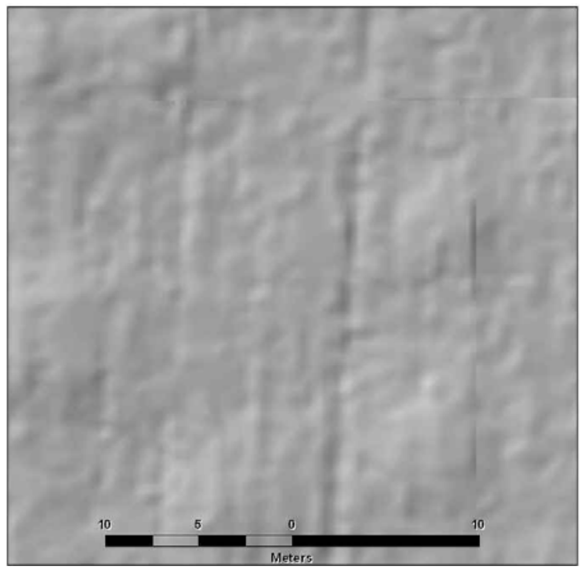
Step 3: Hillshade created from DEMs (DEMs showing underneath). Gaps are once again slightly larger.

In theory, this effect may be overcome by combining all of the lidar points into a single file and processing to a single TIN and DEM. In practice such an approach would create a point file that was too large to be processed using any available software. A more practical alternative is to specify delivery of overlapping point blocks. DEMs are then created from each separate point block and then merged. The following images show the result for the same area shown in the previous images. The overlapping point files created a surface model free of gaps.

Figure 3-10



Lidar points showing overlapping point blocks



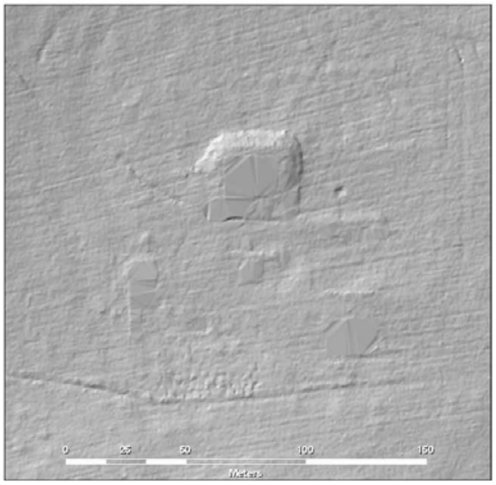
Hillshades from same area showing no gaps.

3.7.5 Detection and Delineation of Potential Munitions Response Sites and Ground Features

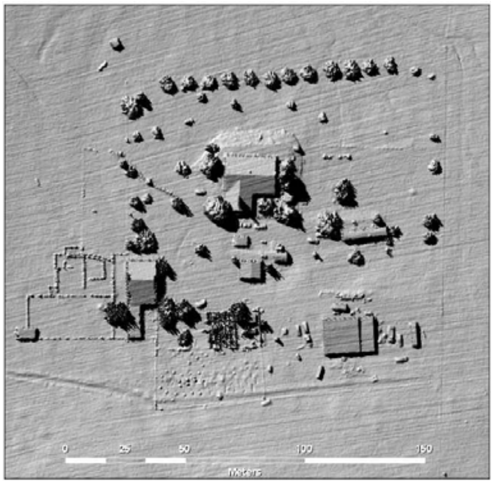
Non-Munitions-Related Features

Once the lidar data had been converted to useable GIS products, the lidar and orthophoto data were examined and individual features noted. The demonstration site contains numerous ground features with a much wider variety than were observed at the Kirtland PBR or Victorville DBT "Y" sites. Some site features were clearly not related to munitions use. These features could be eliminated from further investigation with relatively high confidence, and were not included as features of interest. Some example non-munitions-relate features are shown in the following images.

Figure 3-11

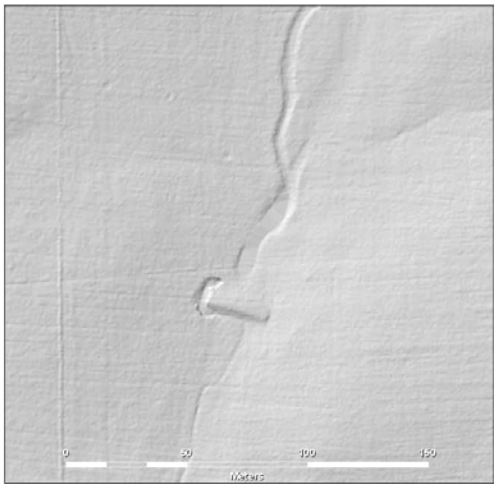


Ground points surface model of potential features.



All points surface model showing house and outbuildings

Figure 3-12

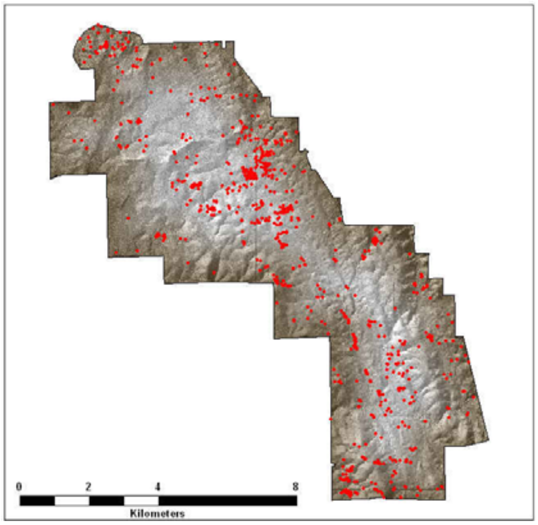


Ground points surface model of potential feature.

Orthophoto showing water impoundment

Features that were potentially related to munitions use were marked and assembled to a GIS point file. A total of 989 ground features were identified. This did not include the individual potential craters in one of the two crater fields, which were too faint, numerous, and overlapping to be counted accurately.

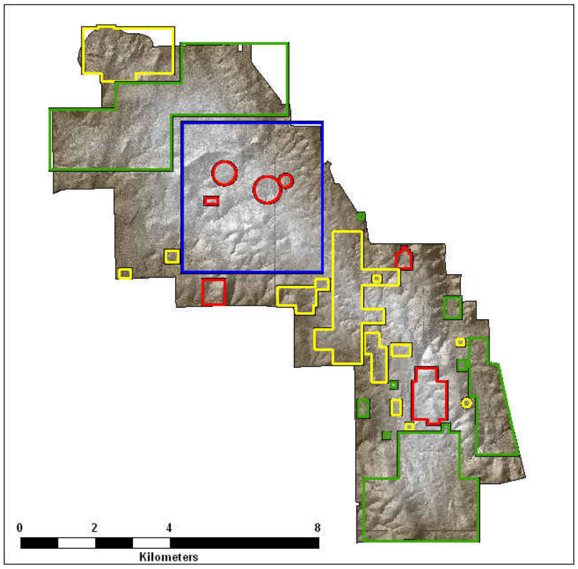
Figure 3-13



First round of feature identification assessment.

The identified features were then examined along with data from the CSM, and grouped into initial areas of interest. These areas are discussed further in Section 4.2, Performance Confirmation Methods, in the light of field verification activities.

Figure 3-14

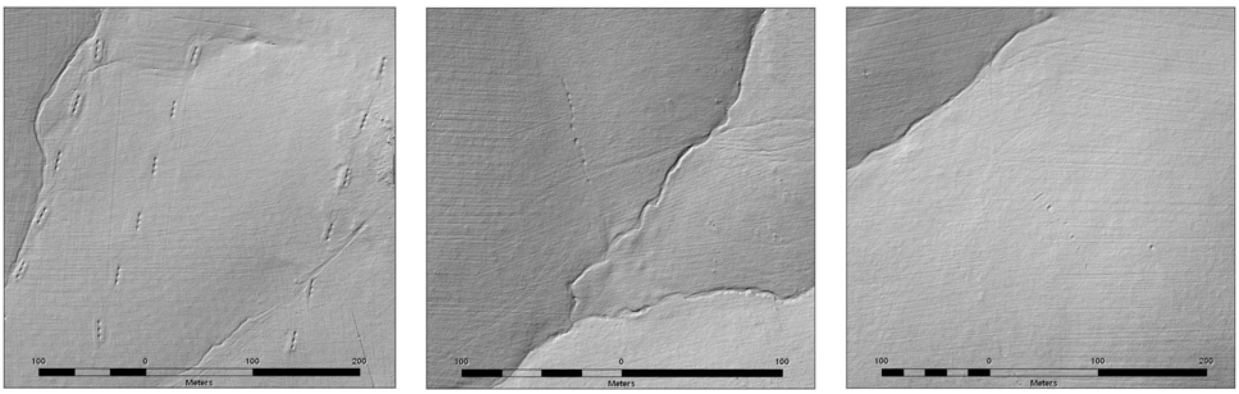


Initial areas of interest.
Likely MEC features: red
High potential MEC features: blue
Potential MEC features: yellow, and
Other features of interest: green

3.7.6 Ambiguous Features

The majority of ground features on the demonstration site were ambiguous, and their origins could not be determined from the lidar and orthophoto data alone with high confidence. Some example ambiguous features are shown in the following images. Generally, these took the form of depressions from 2 – 5 m in size, appearing semi-randomly or in a variety of groups.

Figure 3-15



Ambiguous ground features

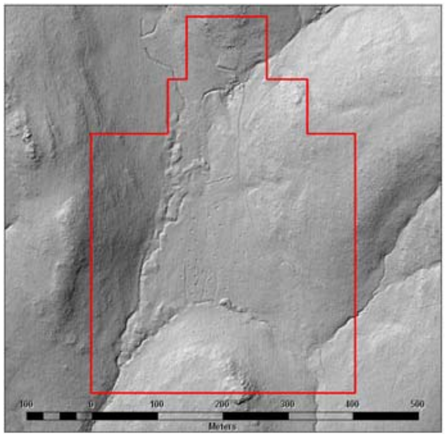
3.7.7 Potential Munitions Use Sites

Five areas on the site could be labeled as potential MRS with relative confidence. These included two possible firing ranges and three potential bombing areas.

Potential Firing Range 1

Potential Firing Range 1 is located in the central western portion of the site. The site consists of a relatively flat, square area to the north, approximately 39 potential craters around 3 m in diameter and 0.5 m deep, and a ship-shaped object approximately 20 by 40 m. To the south is a low hill. The area is within Range 8 from 1956 and Range 7 from 1959, both of which were designated as ground ranges where 57mm Recoilless Rifle, 60mm Mortar, .50 caliber weapons and shape charges were used.

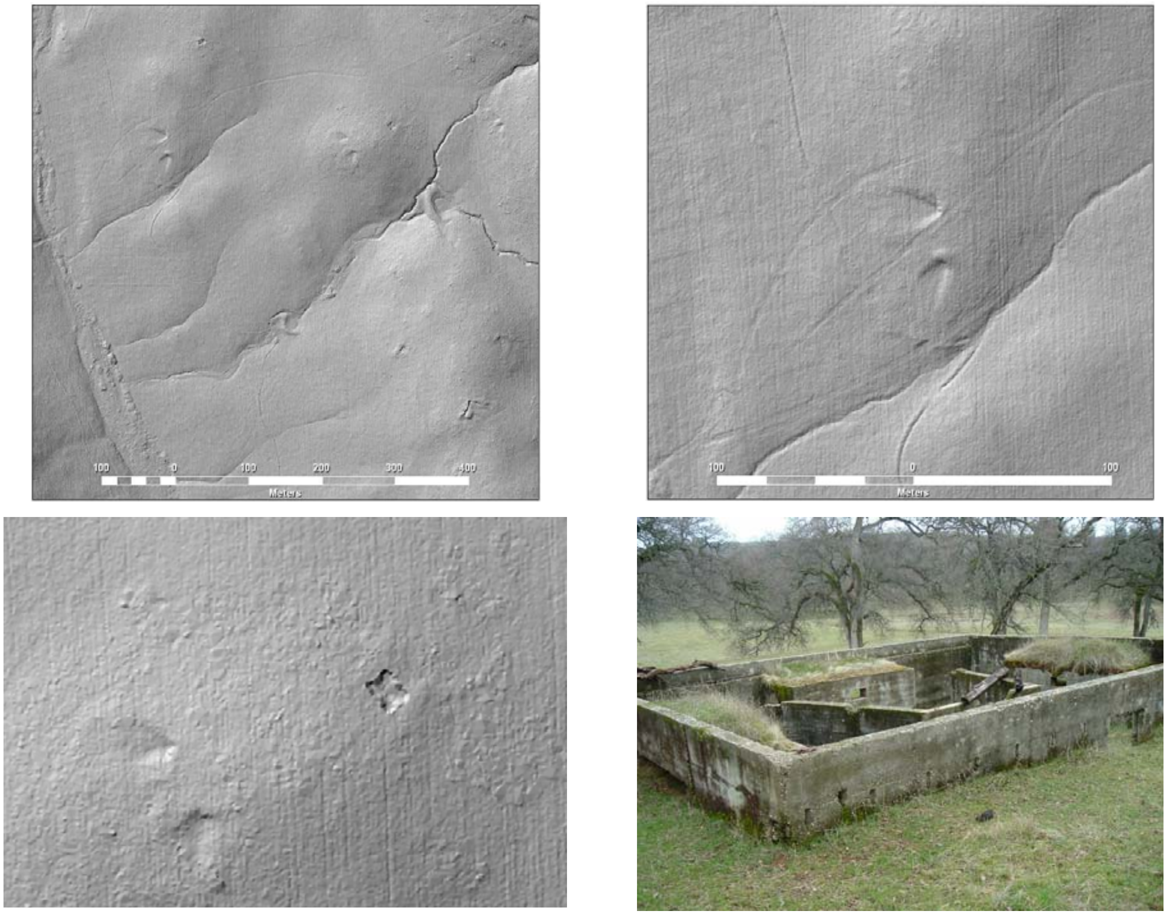
Figure 3-16



3.7.8 Potential Firing Range 2

Potential Firing Range 2 is located in the south part of the study area. The area consists of 13 pairs of fan-shaped level areas, along with 7 bunkers. The area is located within the Primary Navy Toss Bomb Target (1956). There is no information available as to the type of munitions used in the Navy Toss Bomb Target. The area is also within the USAF I.G. Training Area (1956) and borders Targets 2 (1956) and 4 (1955). Target 2 was used for high explosive charges up to 250 lbs. The USAF I.G training area was used for small arms, signals, booby traps, trip flares and other pyrotechnics.

Figure 3-17



This area contains 13 pairs of fan-shaped firing points and 7 scattered bunkers.

3.7.9 Potential Bombing Area 1

Potential Bombing Area 1 is a bull's eye target located in the northern portion of the site, and is the clearest target object on the site. The target consists of 4 rings, the largest of which is approximately 300 m (984 ft) in diameter. The area contains numerous craters ranging up to approximately 3 m in diameter and 0.1 m deep. This target is located between Target 3 and Navy Target T-63 in the CSM, which was used for HE bombing practice from 1948 to 1955. The location of Bull's-eye Target 1 is not within the mapped location of either CSM Target 3 or Navy Target T-63. It appears most likely that this is the HE bombing target, and the maps accompanying the initial CSM are somewhat erroneous.

Figure 3-18

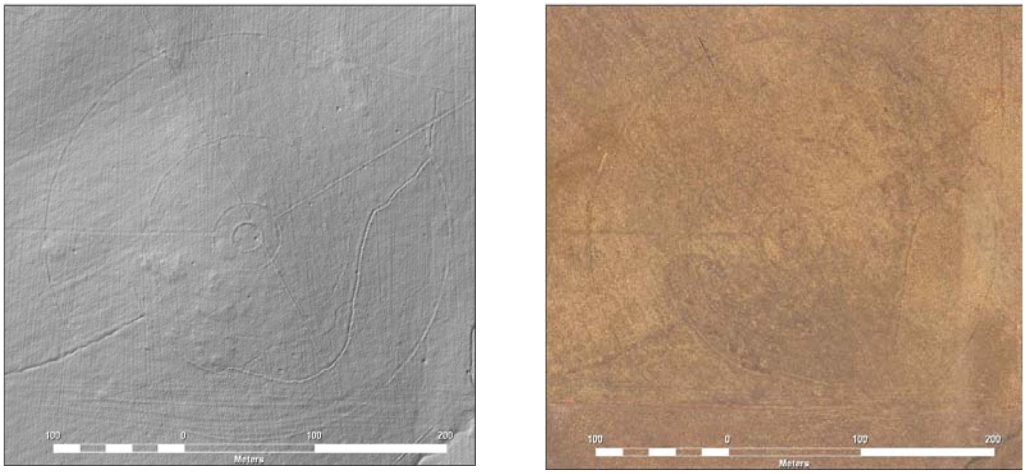
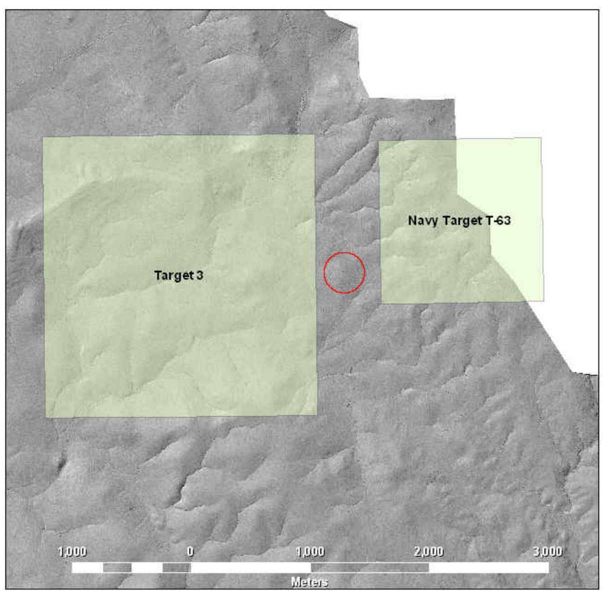


Figure 3-19



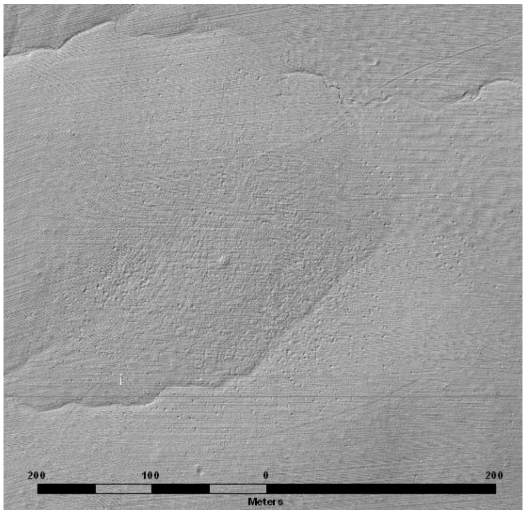
Bull's-eye Target 1 with CSM Target Areas 3 and T-63

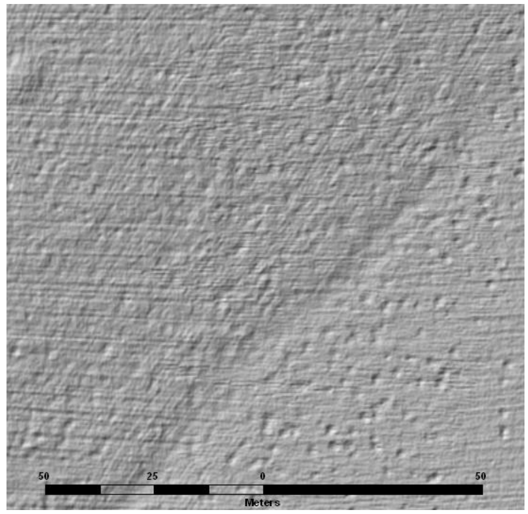
3.7.10 Potential Bombing Area 2

Potential Bombing Area 2 is located in the north central portion of the site. This area consists of several hundred potential craters, approximately 1 m to 3 m in diameter and up to 0.40 m deep. The target area contains a mound (now approximately 0.70 m tall) that may represent a target

center point. The area is within Target Area 6 from the CSM, which was used for live bomb releases for Shoran training between 1955 and 1959.

Figure 3-20

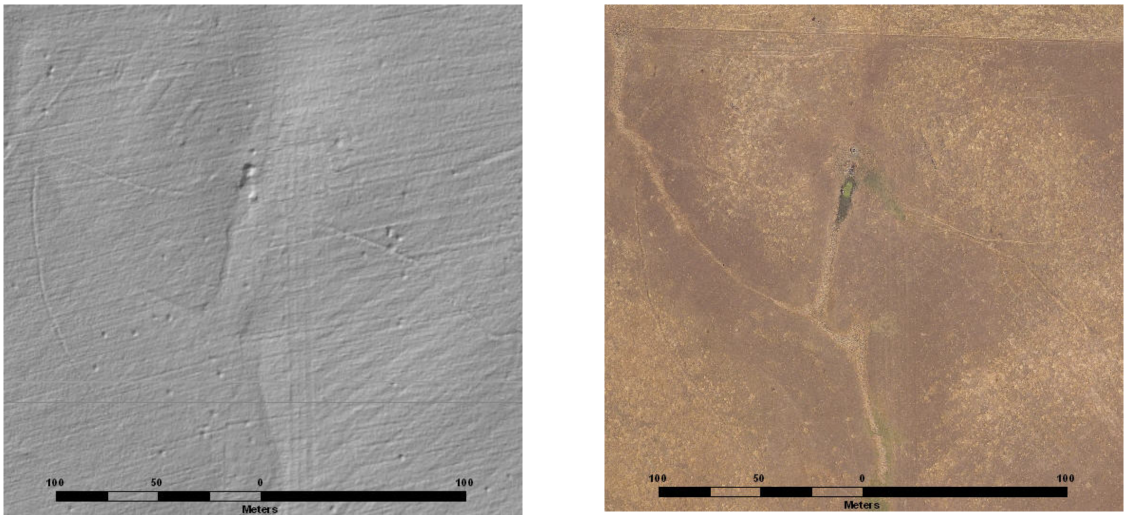




3.7.11 Potential Bombing Area 3

Potential Bombing Area 3 is located in the north central portion of the site. This area consists of several hundred potential craters, approximately 1 m to 3 m in diameter and up to 0.40 m deep. As with Potential Bombing Area 2, the area is within Target Area 3 from the CSM, which was used for live bomb releases for Shoran training between 1955 and 1959. The area may represent a second target area within Target Area 3.

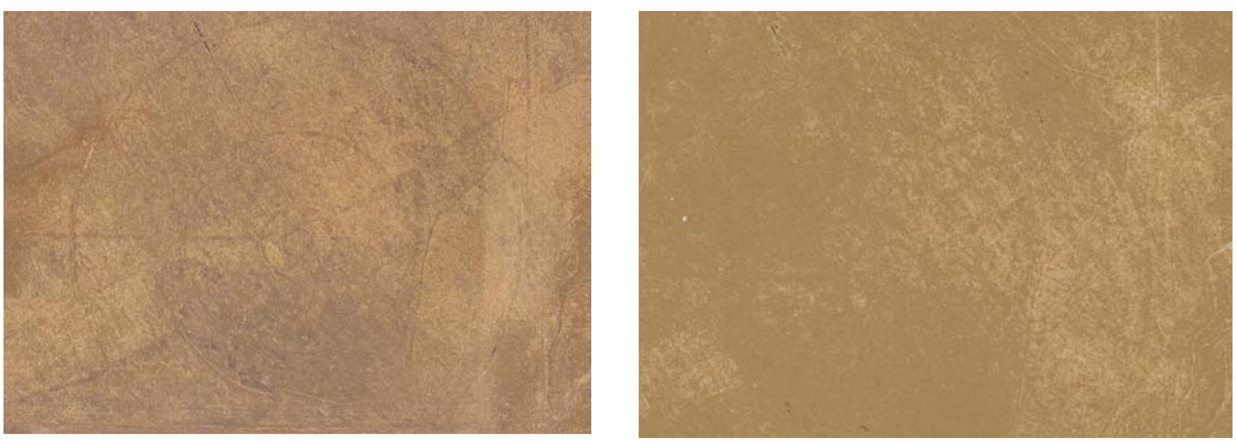
Figure 3-21



3.7.12 Data Density Effects - Orthophotos

The Former Camp Beale demonstration was not designed to test the effects of orthophoto data density. During the first phase of the WAA Pilot Program, orthophotos were collected at 10 cm and 20 cm pixel sizes at the Kirtland PBR site; and based on the results of this test; collection at subsequent sites was only at 10 cm. However, by coincidence the Army Corps of Engineers already had available orthophotography of the site (in the MrSID compressed format) at a 30 cm (1 foot) pixel resolution. Consequently, it was possible to compare this orthophoto data to the 10 cm pixel data collected as part of the demonstration.

Figure 3-22



Bull's eye aiming target: 10 cm pixel orthophoto

Bull's eye aiming target: 30 cm (1 ft) pixel orthophoto

In at least one area of the site, the difference between the two data sets was striking. The target rings in Potential Bombing Area 1 are clearly visible in the 10 cm orthophoto, but are virtually undetectable in the 30 cm orthophoto.

3.7.13 Data Density Effects - Lidar

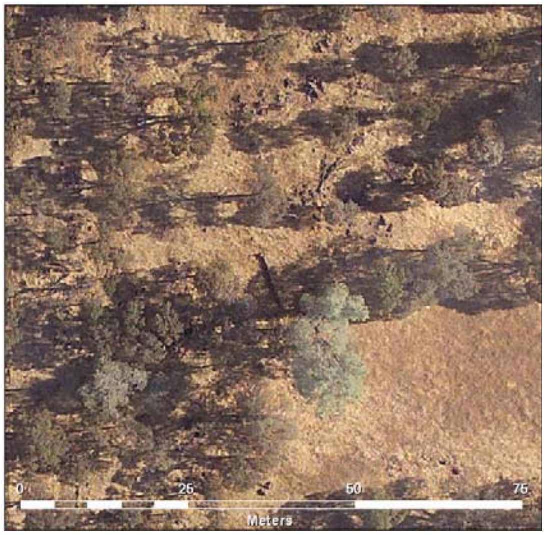
Lidar data density is based on the average number of lidar points per square meter. While these average values are useful as general descriptors, lidar data density actually varies considerably over the ground surface, a complex phenomenon that is discussed in Appendix C of the final report for the Kirtland PBR and Victorville DBT "Y" sites. Lidar data was obtained at the following overall data densities:

Table 3-2
Achieved Lidar Data Densities

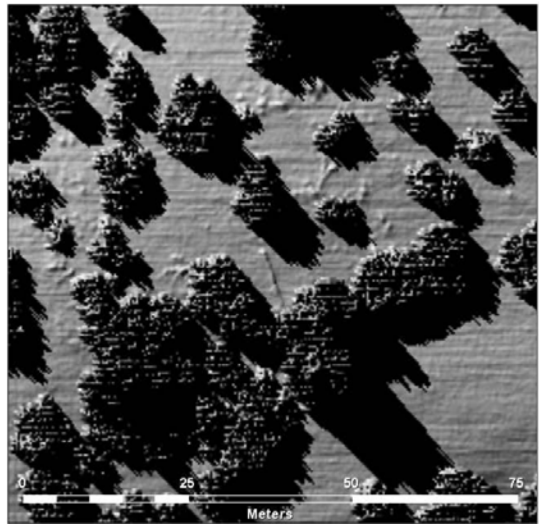
Flight	Overall point density (pts/m2)
450 m flight	13.8
300 m flight	13.7

The achieved data densities are considerably higher than the performance criteria of 3 pts/m^2 for the 450 m flight and 5 pts/ m^2 for the 300 m flight. These high densities resulted from two factors. First, the sensor speed was increased to 75 kHz, compared to the 45 kHz and 50 kHz used at the previous sites. This decision was a result of a request to the vendor to obtain higher densities if the equipment allowed. The second factor was that flight speed was much slower than planned due to the high ambient air temperatures. These two factors combined to yield much higher densities than planned. In turn, these high lidar densities allowed for the creation of exceptionally detailed surface models. For example, in the following images, individual small tree trunks can be seen on the ground surface.

Figure 3-23



10 cm orthophoto showing fallen trees and rocks on the ground.



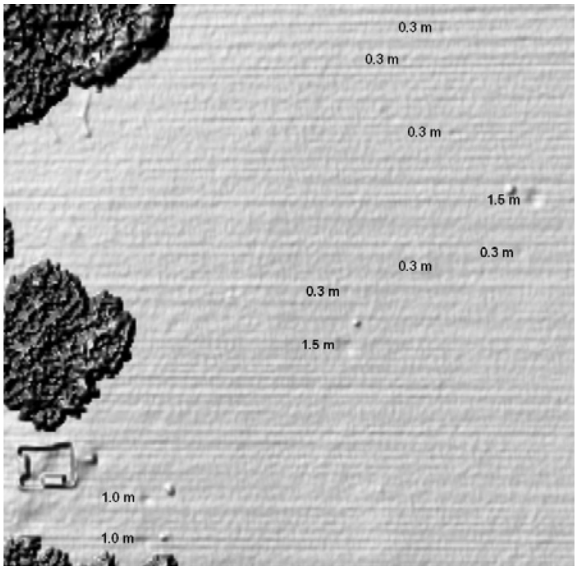
All points lidar surface model hillshade of the same area showing the same objects in the lidar image.

3.7.14 Detection of Test Craters

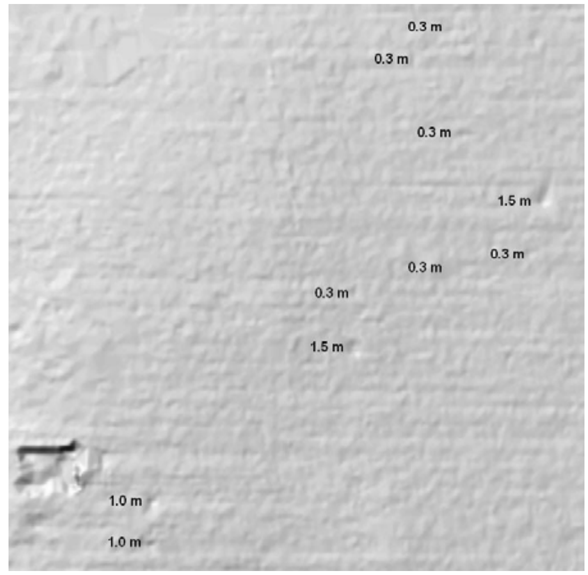
At the Kirtland and Victorville test sites, detection of test craters using lidar improved as the data density increased. At both sites, test craters at 1.0 and 1.5 m in diameter were reliably detected at all data densities (1.5 – 5 pts/m^2); while the 0.30 m (1 foot) test craters were not detected at any data density acquired.

At the Former Camp Beale site, results were similar despite the higher data densities: the 1.0 m and 1.5 m craters were reliably detected, while the 0.30 m test craters were not, as shown in the following images.

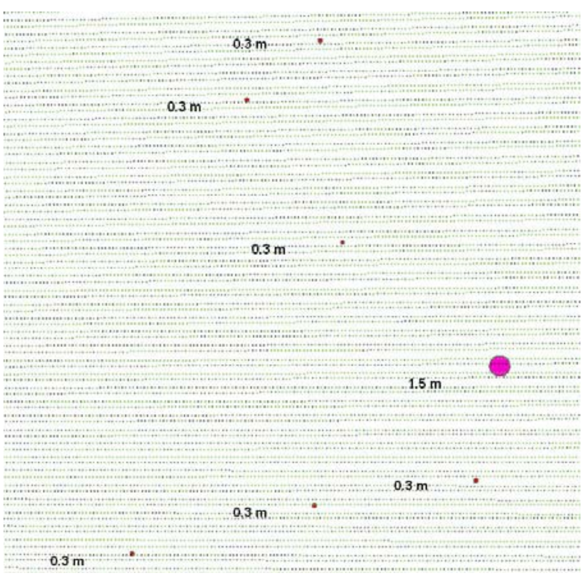
Figure 3-24



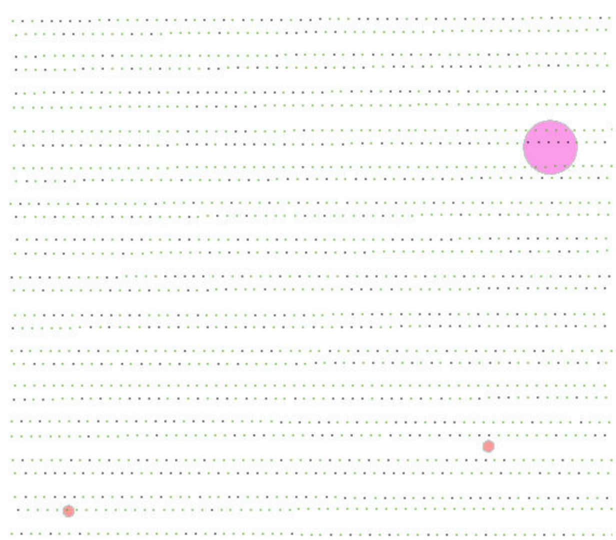
All points surface model showing test craters.



Ground returns surface model showing test craters.



300 m lidar points, (both ground and non-ground). Several of the 0.3 m craters appear to lie between the rows of lidar points.



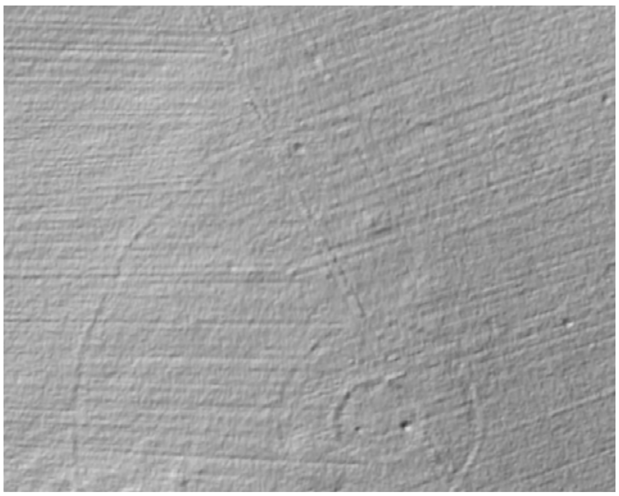
Portion of the image to the left, 300 m lidar points, (both ground and non-ground). One 0.3 m crater has a lidar point, one does not.

These images show that even with a high point density of 13.8 pts/ m^2, lines of individual lidar points are frequently spaced sufficiently far apart so as to miss the 0.3 m craters. While some craters of this size can be (and were) detected, the probability of detection is far from 100%

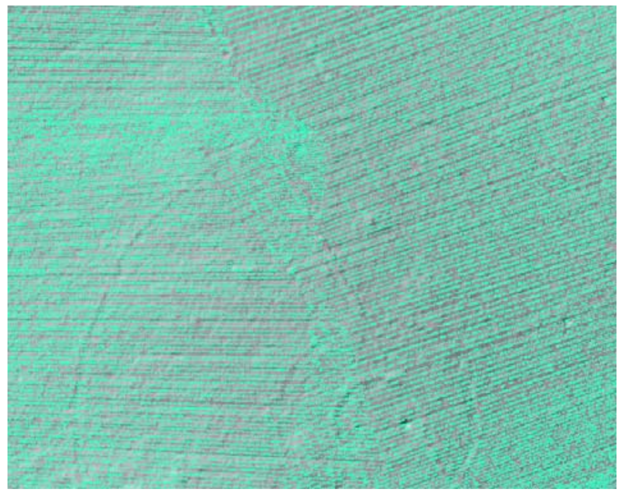
3.7.15 Data Artifacts and Noise Effects

As at the previous demonstration sites, the Former Camp Beale lidar data showed “corduroy” effects roughly 0.05 m deep in areas of relatively flat, smooth terrain. The size of the anomaly is well within the vertical accuracy specifications for lidar data. This is a common lidar artifact, generally believed to result from small errors in the GPS, IMU and laser range finder that cannot be adjusted out during data processing. The images below show the relationship between the observed “corduroy stripes” in the modeled ground surface and the lines of lidar points.

Figure 3-25



“Corduroy” effect

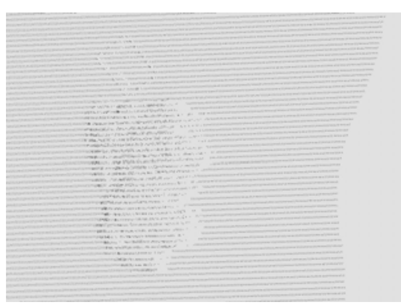


“Corduroy” effect with lidar points

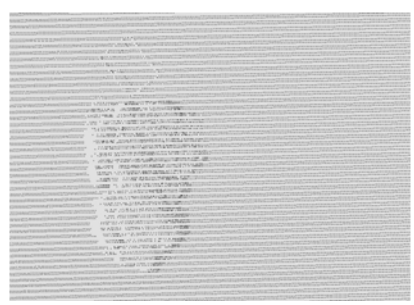
A previously unnoted lidar data effect was encountered in the Former Camp Beale lidar data. Trees and other tall objects caused a “shadow” effect in the lidar points as shown in the following images.

Figure 3-26

Orthophoto of tree within the study area



Lidar points of the same tree. The flight line centerline is to the left (west) of the tree.

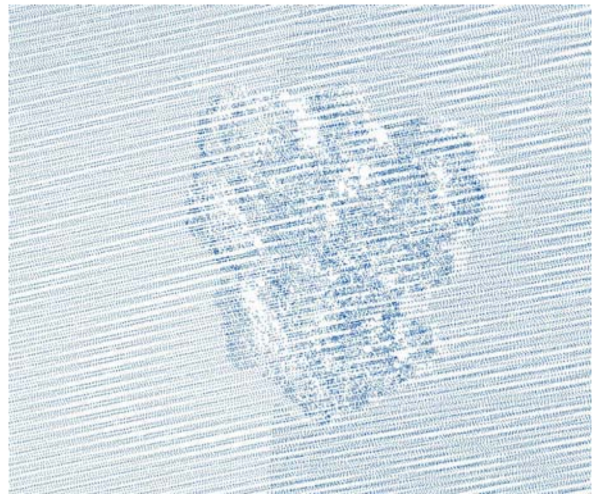


Lidar points of the same tree. The flight line centerline is to the right (east) of the tree.

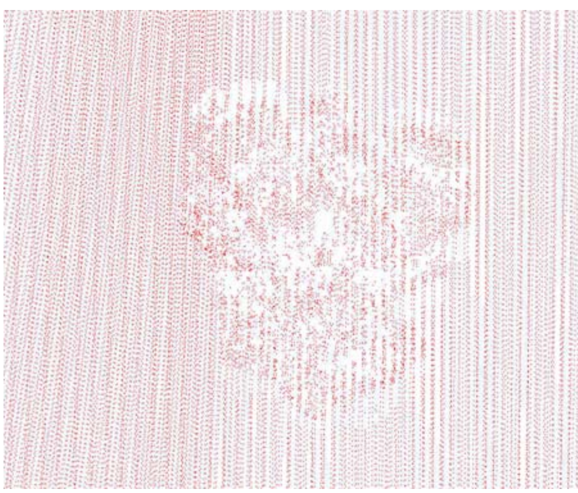
This effect results from the fact that all but a few lidar points approach the ground surface at an angle rather than straight down from the aircraft. Consequently, lidar points can be blocked from the ground surface by trees or buildings, creating “shadowed” areas with few or no returns. Ground features in such areas will not be detected. This effect may be somewhat mitigated by overlapping flight lines or conducting two lidar flights, as shown in the following images:

Figure 3-27

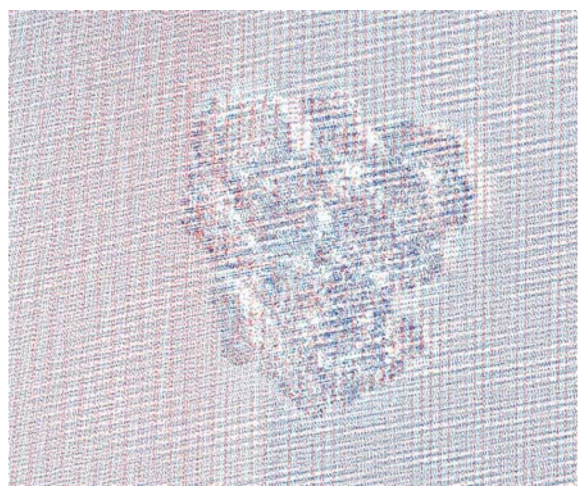
Orthophoto.



Lidar points, 300 m flight, showing small shadowed areas with few to no lidar points.



Lidar points, 450 m flight, showing different areas with few or no lidar points.



Lidar points, both flights combined; areas with few or no lidar points are largely eliminated.

3.7.16 Effects of Flight Line Orientation

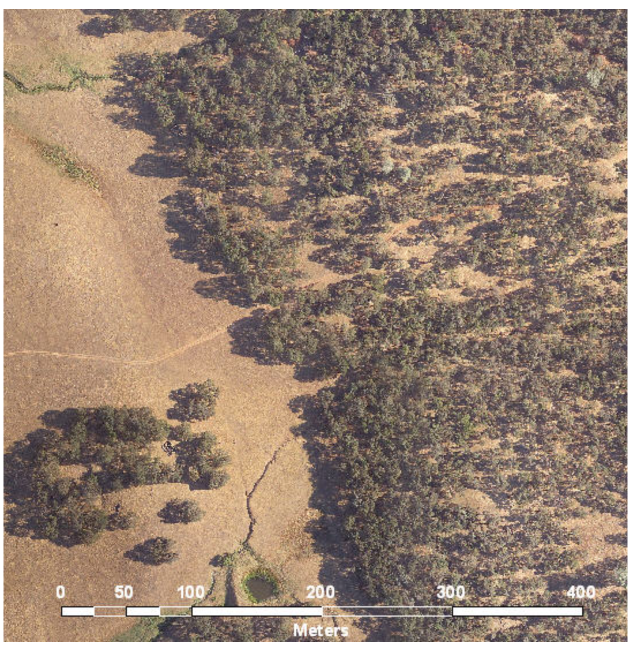
At the Kirtland site, faint roads were detected differently by lidar with different flight line orientations. For the Camp Beale site, this effect was not observed, possibly because all of the north/south and east/west roads were sufficiently large and distinct, and possibly because of the higher lidar data density obtained.

3.7.17 Vegetation Effects

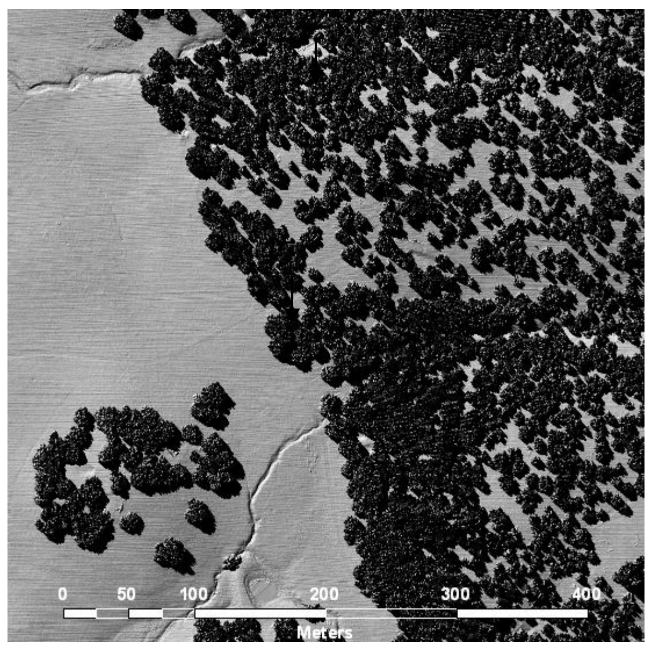
As a light-based technology, lidar does not penetrate vegetation. Nevertheless, lidar is often successfully used to model the ground surface under vegetation, since lidar points will often fall in the many gaps between foliage. In practice, lidar has been used to model ground surfaces in all but truly closed canopies.

However, while some lidar points will penetrate to the ground surface in vegetated areas, most will not. Consequently, the surface model under vegetative cover will be less detailed. As a preliminary attempt to quantify this effect, two areas of ¼ km^2 were modeled. A grid of 2 m cells was created, with each cell assigned the percentage of lidar returns that were reflected from a point 3 feet or higher from the ground surface. At these two areas, the forested areas blocked from 50% - 80% of the lidar points, while in dense brush over 90% of the lidar points were blocked. Under the trees, good modeling of the ground surface was nevertheless achieved. This may have been a result of the high overall lidar data densities involved. In the area of dense brush, the vegetation effect caused serious degradation of the surface model. The effect is shown in the following images.

Figure 3-28

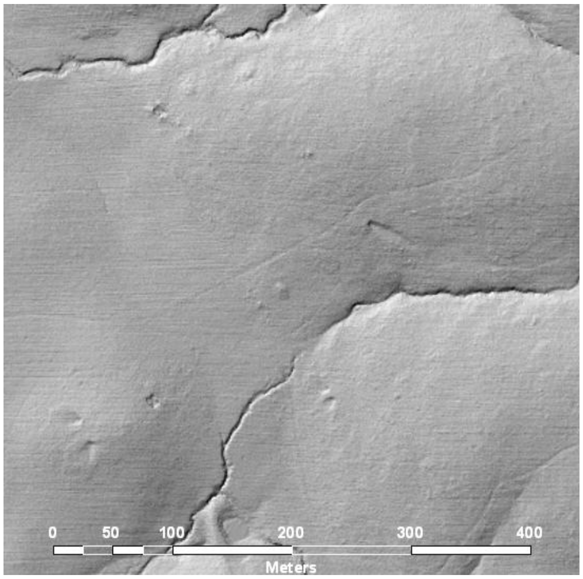


Orthophoto showing open area and trees.

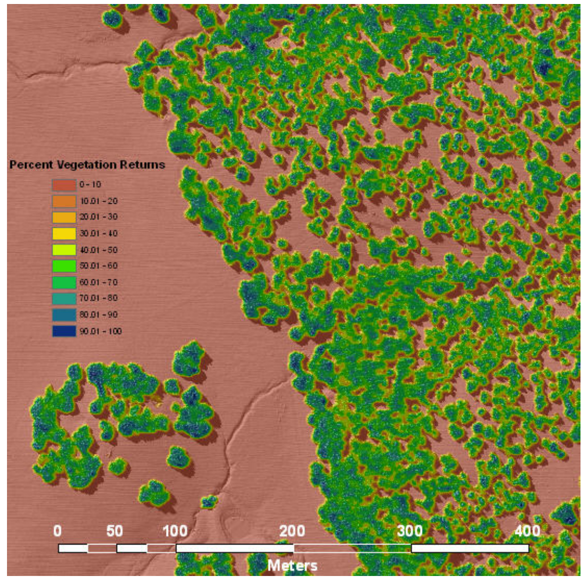


All points lidar surface model.

Figure 3-29



Lidar ground surface model.

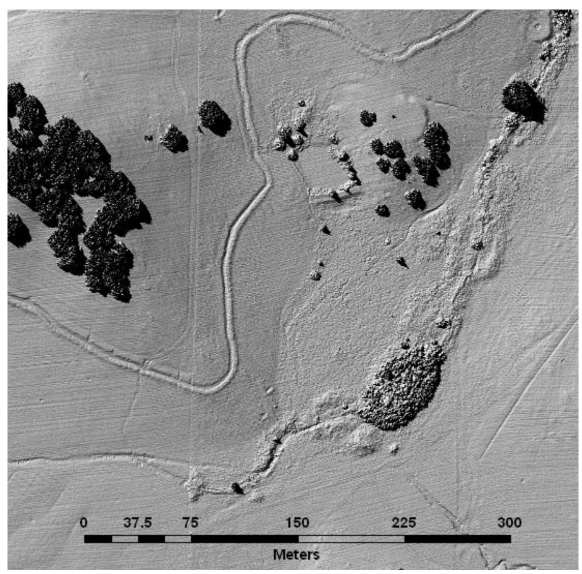


Density map showing the percentage of lidar points reflected from vegetation over 3 ft. in height.

The following images show an area containing both trees and an area of dense brush.

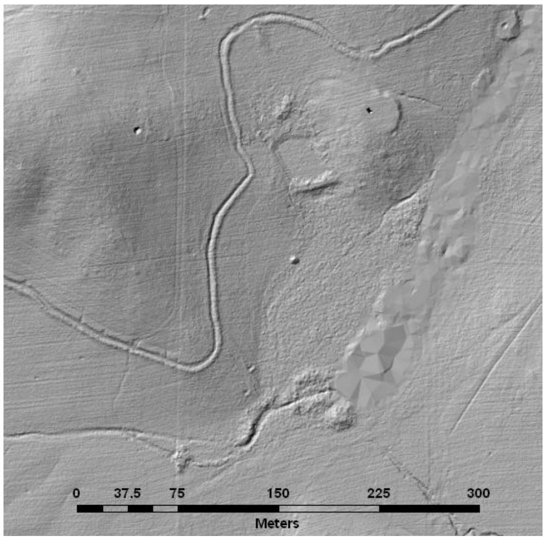
Figure 3-30

Orthophoto showing open area, trees and brush.

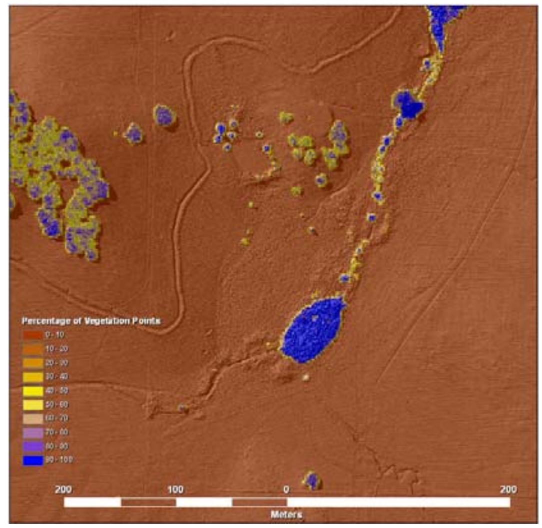


All points lidar surface model.

Figure 3-31



Lidar ground surface model, showing good quality for the treed area and serious degradation for the brushy area.



Density map showing the percentage of lidar points reflected from vegetation over 3 ft tall.

These preliminary results indicate that in vegetated areas, lidar data densities should be higher and that in areas with dense vegetation, confidence in the lidar surface model will be lower. Vegetation effects will be the subject of further investigation.

3.7.18 Lidar and Orthophoto Positional Accuracy

Positional accuracy specifications were established in the Demonstration Plan for each site, and repeated in Table 4-1, Performance Criteria. Lidar and orthophoto data met the positional accuracy criteria established. The following table presents the overall positional accuracy results for the two sites.

Item	Performance Criteria	Results (m)	
Lidar vertical accuracy	Avg. dz: +/- 0.15 m compared to control points	Lidar to ESTCP control points 300 m flight 450 m flight	Avg. dz: 0.008 m Avg. dz: 0.095 m
Lidar horizontal accuracy	Avg. dx/y: +/- 0.65 m compared to control points	Average x and y displacement (dx and dy) for all control points for each flight.	300/450 m flights Avg. dx: 0.15 m Avg. dy: 0.21 m
Orthophoto horizontal accuracy	Avg. dx/y under 3 pixel widths compared to control points	10 cm orthophotos to control points	450 m flight Avg. dx: 0.19 m Avg. dy: 0.24 m
Orthophoto to lidar alignment	Avg. dx/dz under 2 pixel widths	10 cm orthophotos to lidar positions	Avg. dx: 0.13 m Avg. dy: 0.10 m

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

Lidar and orthophoto data collected for this demonstration met the performance criteria related to data collection, data procession, site coverage and positional accuracy.

MRS were detected and the location of one bombing target was corrected from the CSM. Numerous ground features were identified. The origin of many features could not be determined from the lidar and orthophoto data alone; however, lidar and orthophoto data was usable to identify features for further investigation.

The following performance objectives are taken from the Technology Demonstration Plan for the site.

Table 4-1
Performance Criteria

Performance Criteria	Description	Primary or Secondary
Pre-mobilization		
Verification of survey control point positions	Verify survey control point locations within at least 3rd order accuracy.	Primary
Lidar data collection and processing		
Area coverage	100% coverage for each flight.	Primary
Lidar point density	Achieve overall lidar point densities of: 300 m flight (1) – 5 pts/ m^2 450 m flight (1) – 3 pts/ m^2	Primary
Lidar vertical accuracy	Vertical accuracy of +/- 15 cm compared to ground survey.	Primary
Lidar horizontal accuracy	Horizontal accuracy of +/- 65 cm compared to ground survey.	Primary
Orthophoto data collection and processing		
Orthophoto area coverage	100% coverage for each flight.	Primary
Orthophoto flight altitude / pixel size	450 m (for 10 cm pixel flight).	Primary
Orthophoto horizontal alignment to Lidar	Lidar and orthophotos aligned so that target features are not displaced in the two data sets.	Primary
Orthophoto horizontal alignment to survey control points	Orthophotos aligned to survey control points so that target features are not displaced.	Primary
Munitions Response Site identification and analysis		
MRS identification	Correctly identify MRS identified in the CSM.	Primary
MRS false alarm rate	No areas incorrectly identified as MRS.	Primary
MRS boundary delineation	Correctly locate MRS boundaries to +/- 15% of ground-truthed area.	Primary
MRS feature identification	Identify features presenting as munitions related (anthropogenic)	Primary

4.2 PERFORMANCE CONFIRMATION METHODS

4.2.1 Demonstration-Level Confirmation Methods

At the demonstration level, effectiveness of lidar and orthophotos was evaluated based on its ability to meet the stated performance criteria given in Table 4-1. The demonstration relied on proven industry methods to assure predictable results, including the use of survey controls, equipment calibration, alignment of lidar points to the survey control points and from one flight line to the next, and QA/QC checks throughout the project. Both lidar and orthophoto data met all data quality specifications.

4.2.2 Program Level Confirmation Methods

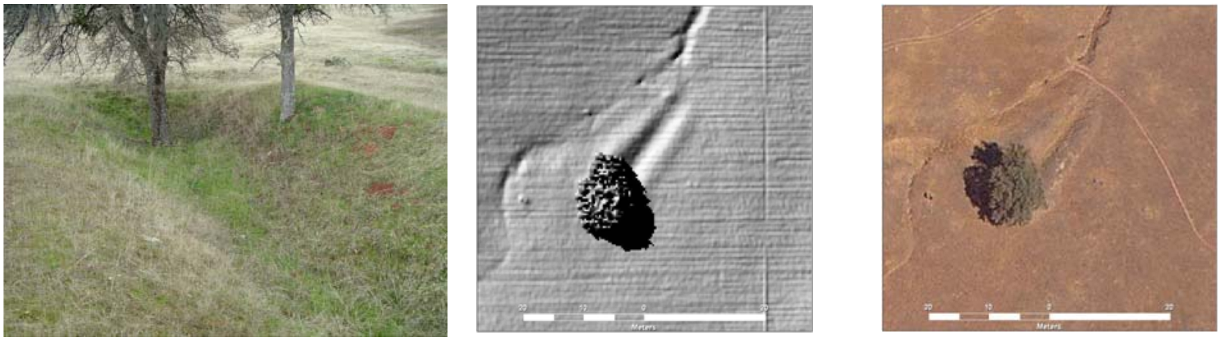
In order to investigate some of the ambiguous features, a field crew visited the site between February 2nd and the 5th, 2007. Over three days of field work, 134 ground features identified from the lidar and orthophoto data were visited, photographed and examined using a Schondstedt hand-held magnetometer. The field crew included senior-level UXO staff with many years of field experience on a variety of sites. Field work was limited to areas where site access could be obtained, which excluded most potential areas of interest.

4.2.3 Distinguishing MEC vs. Non-MEC Features

Once in the field, some ambiguous features could be resolved with a relatively high level of confidence. Some of the characteristics of the ground features could be applied to subsequent re-analysis of the lidar and orthophoto data in the office, including the following:

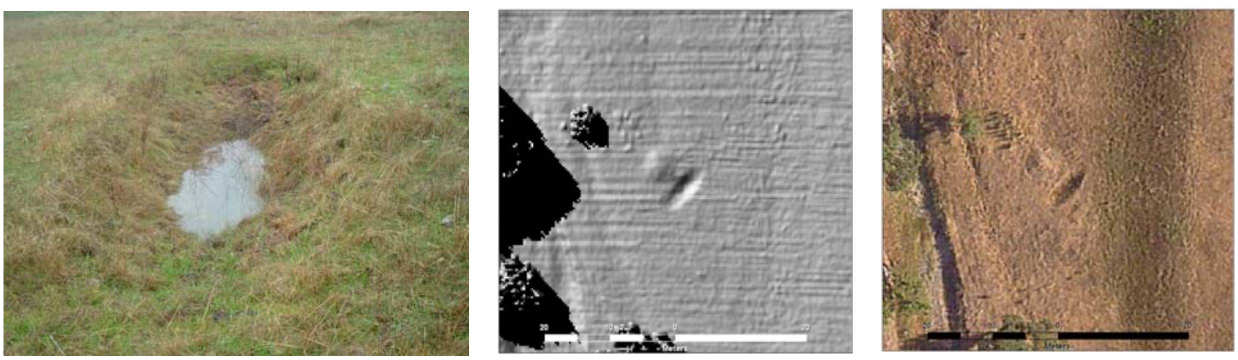
Shape. Some depressions were more rectangular than round, and sharply resembled depressions from earth-moving machinery. These depressions did not resemble craters. This rectangular shape could often be seen in the lidar data, especially at the high lidar data density for this site.

Figure 4-1



Rectangular ground feature. Shape did not resemble crater.

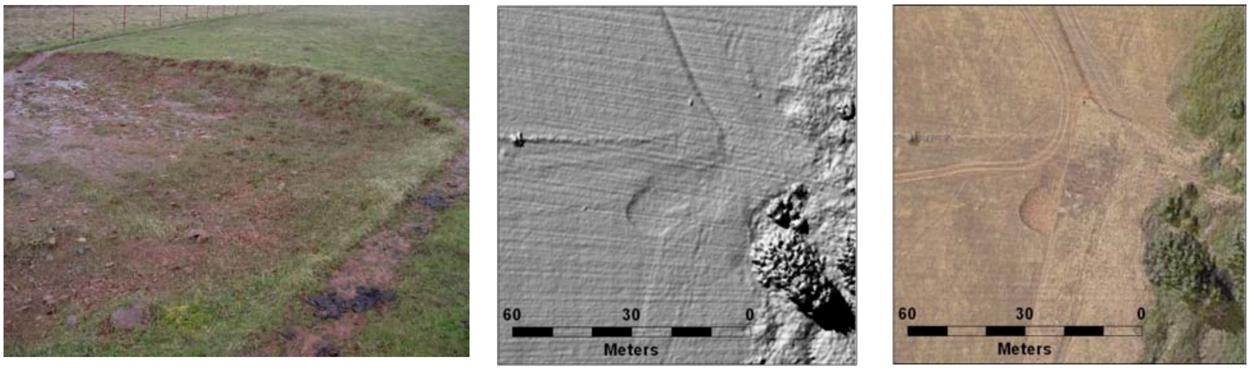
Figure 4-2



Rectangular ground feature. Shape did not resemble crater.

<u>Size.</u> Some features that were roughly circular were too large to be likely craters. This was especially true where such craters appeared in areas with no history of HE use.

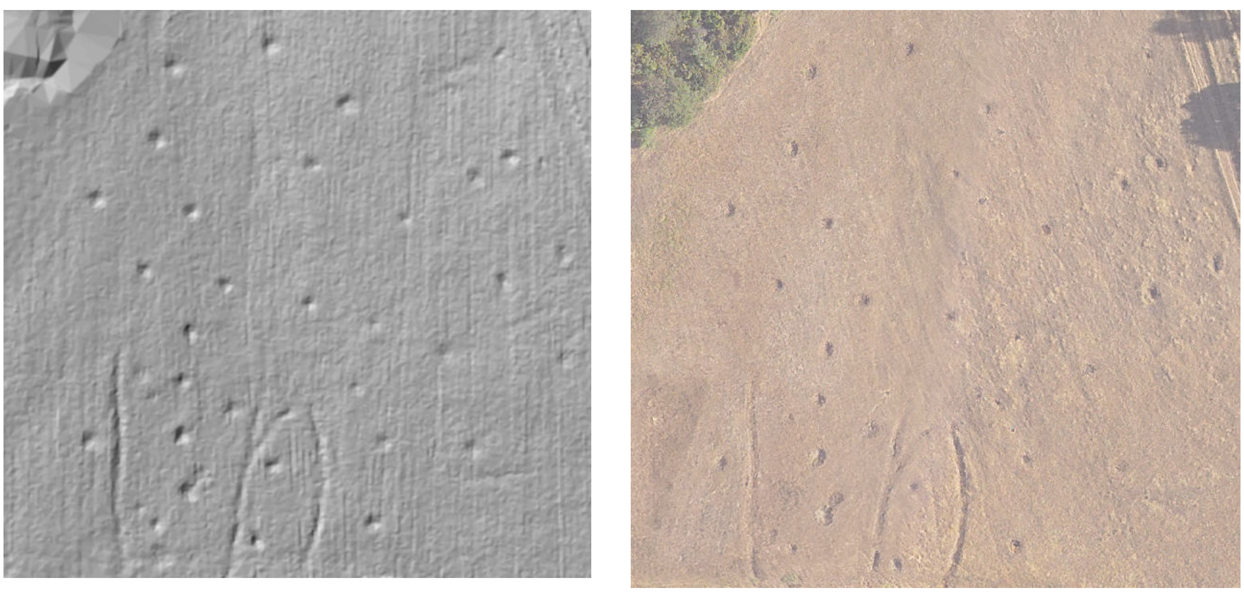
Figure 4-3



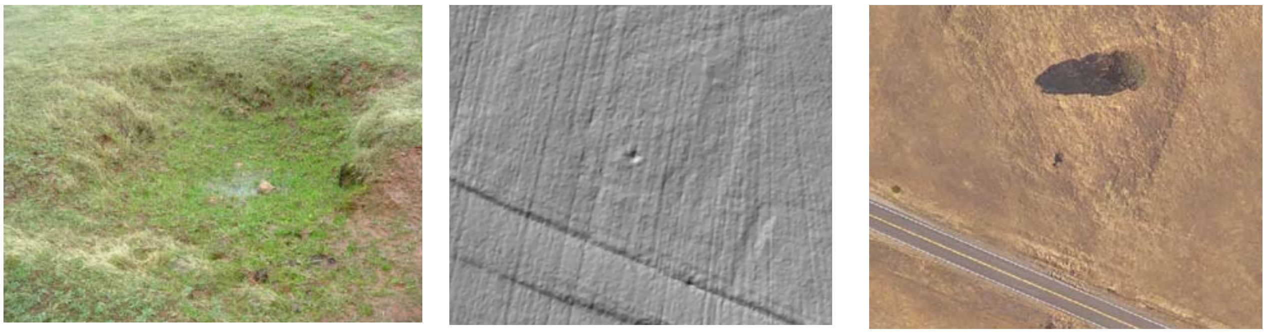
Roughly circular depression, roughly 10 m in diameter. Likely too large to be likely a crater.

Clustering. Individual depressions, located away from other depressions or other features, were judged to less likely to be related to munitions use.

Figure 4-4



Clustered potential craters.



Isolated depression away from other features.

Correlation with CSM target areas. The Former Camp Beale site contains numerous, overlapping ranges, including bombing ranges, firing ranges and training ranges. Information regarding the historic use of many of these ranges is scanty, and sometimes contradictory. For the purposes of validating feature classifications, the procedure used was as follows:

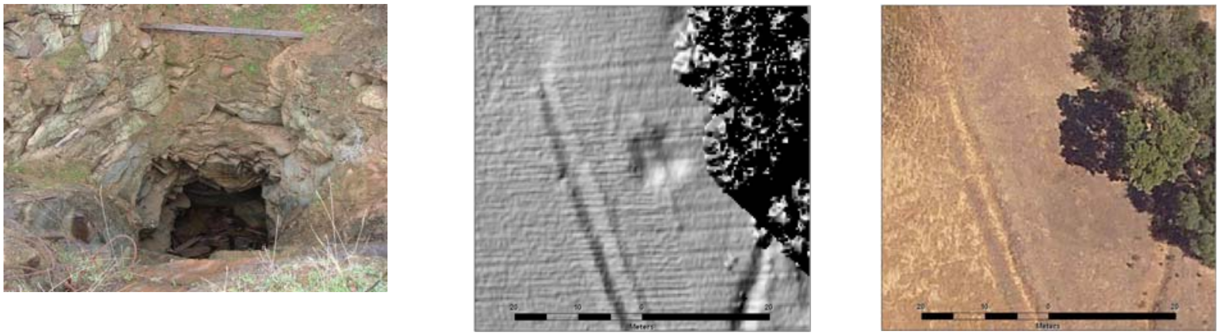
- When looking at potential craters, only HE bombing ranges were considered. These included Target 2 (250 lb), Target 3 (100 lb), Navy T-63 (25, possible 250 lb and 500 lb)

- When looking at the one bull's eye ring, only Target 3 was considered. This target was used for 100 lb HE bombs and practice bombs, and the CSM states that remnants of a bull's eye ring were detected in the NE portion of the site. This is consistent with the location of Potential Bombing Area 1, NE of and outside the boundary of Target 3.

- When looking at other features other than potential craters, firing ranges and training ranges were considered if their use appeared consistent with the types of features observed.

Other characteristics were clear in the field but more difficult to apply to subsequent analysis of the lidar and orthophoto data. In particular, some small, round depressions were sometimes found to be old mine shafts. In the lidar and orthophoto data, it remained difficult to identify these correctly.

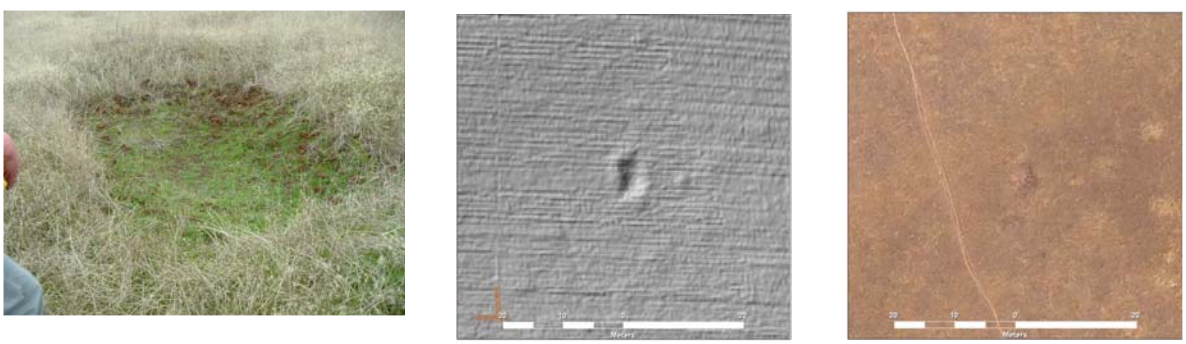
Figure 4-5



Suspected mine shaft.

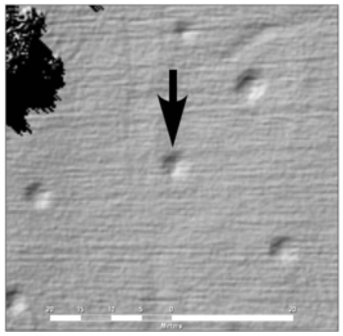
Some features showed positive magnetometry responses, and one piece of ordnance-related scrap was found on the surface during the field visit. However, some crater-shaped features had positive and others negative magnetic response, and there was no clear correlation between magnetic response and the shape of the feature. This finding reinforces the necessity of following the use of lidar and orthophotos with technologies such as magnetometry or EMI that directly detect ordnance components.

Figure 4-6



Ground feature with negative magnetic response.

Figure 4-7



Ground feature with positive magnetic response.

Of the 134 features examined in the field, 118 (88%%) showed no evidence of munitions use, and 16 (12%) showed positive magnetic response or other evidence of munitions use. These results were judged to have relatively high confidence.

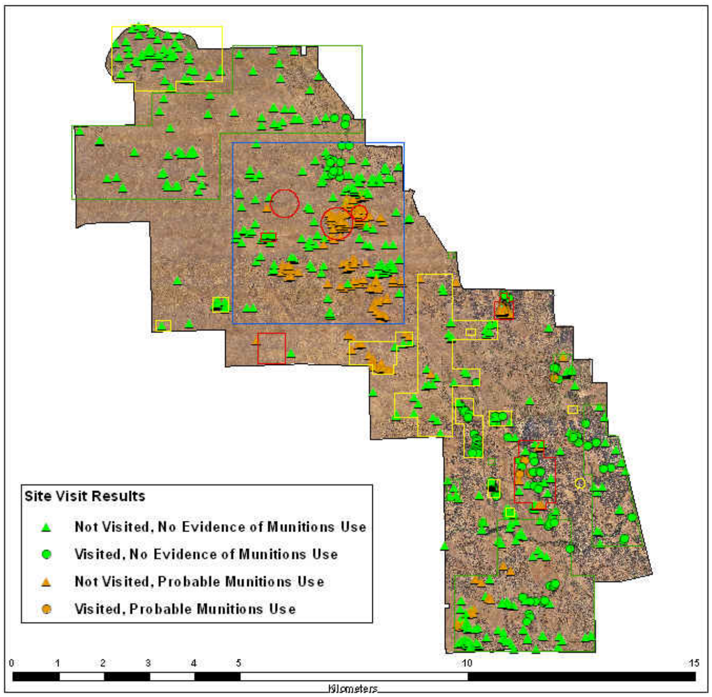
Following the field visit, the UXO staff person who had led the field work examined the lidar and orthophoto data for the features that had not been visited, and applied the results of the field visit, including the factors discussed above, to make a professional judgment as to the likelihood of munitions origin. Of the 856 features that were not visited, 583 (68%) were evaluated as no evidence of munitions use and 273 (32%) were evaluated as probable munitions use.

These office evaluations were judged to have only medium confidence, based on the lack of magnetometry results and the finding that potential craters with and without positive magnetic response could have similar shapes. Further site investigation would be warranted to increase this confidence level.

4.2.4 Correlation with Areas of Interest

Once the individual features had been re-evaluated, the original Areas of Interest were also re-evaluated in the light of the field visit, and their assessments updated.

Figure 4-8

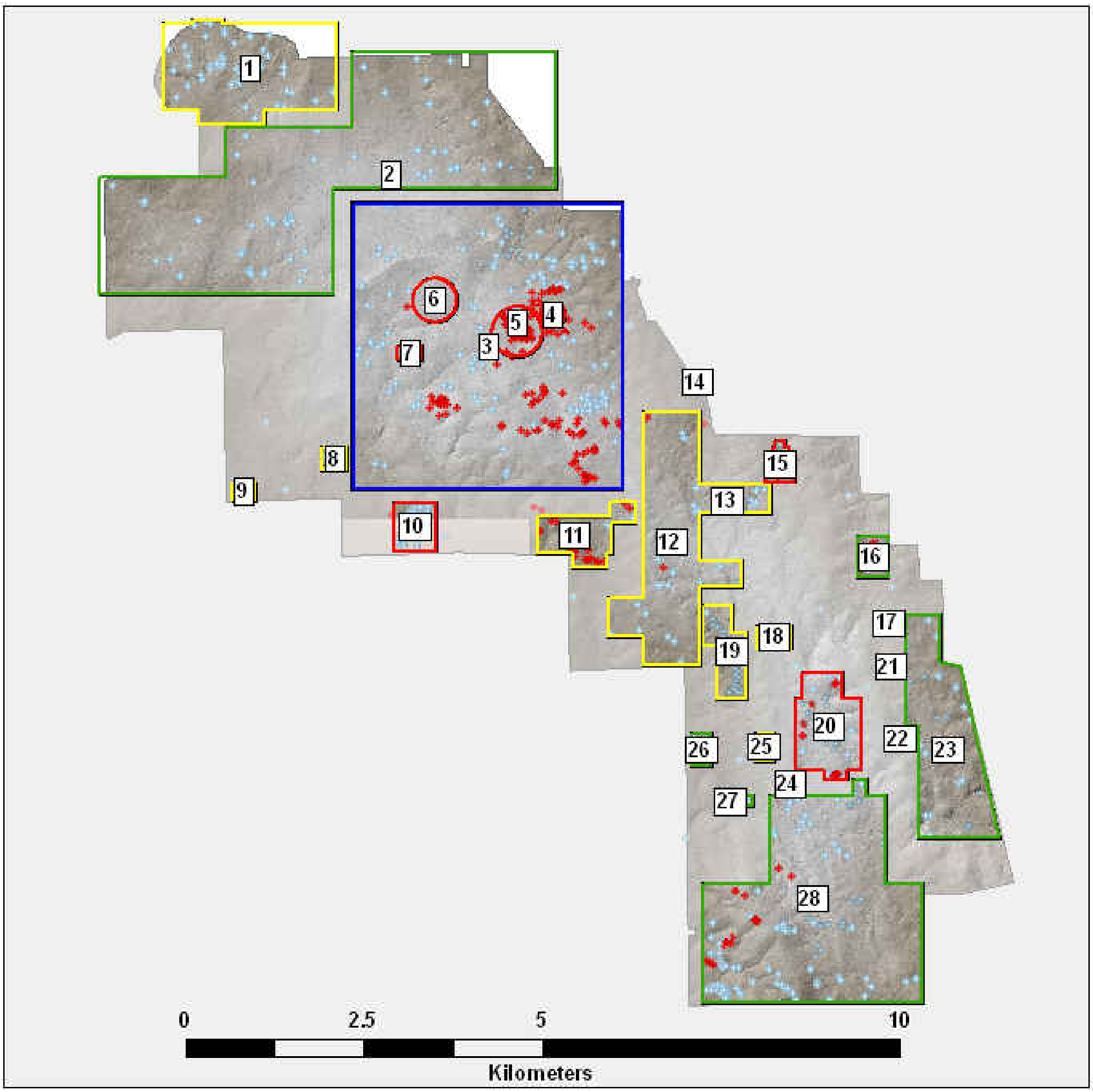


Results from Camp Beale Site Visit

Examination of the original areas of interest in the light of the field results showed that the original assignments were only roughly accurate. This finding is consistent with the ambiguous nature of many of the features. The following images illustrate some of the comparisons between the field work and the original areas of interest.

Figure 4-9 – Initial and Subsequent Analysis

Initial Areas of Interest

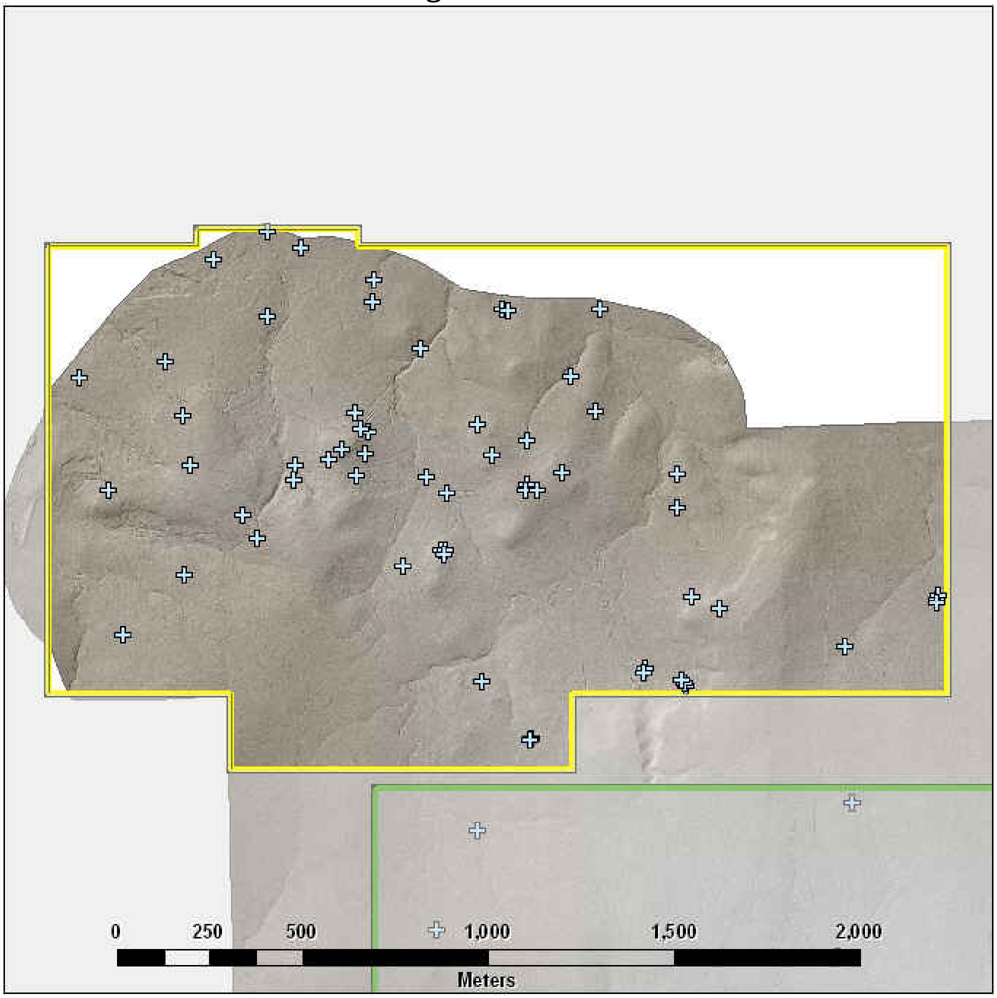


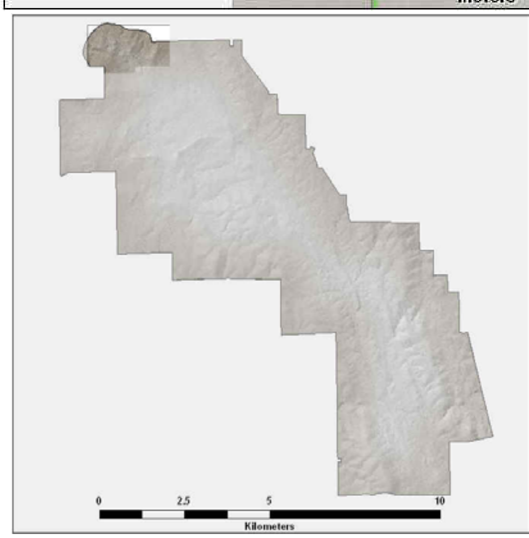
Red: Likely MEC Features
Blue: High Potential MEC Features
Yellow: Potential MEC Features
Green: Other Features of Interest

In the figures that follow, the following symbols show whether the feature was inspected during the site visit, and whether either the field visit or subsequent inspection by UXO staff showed evidence of munitions use:

Ñ	Not Visited, No Evidence of Munitions Use
Ñ	Not Visited, Probable Munitions Use
Ê	Visited, No Evidence of Munitions Use
Ê	Visited, Probable Munitions Use

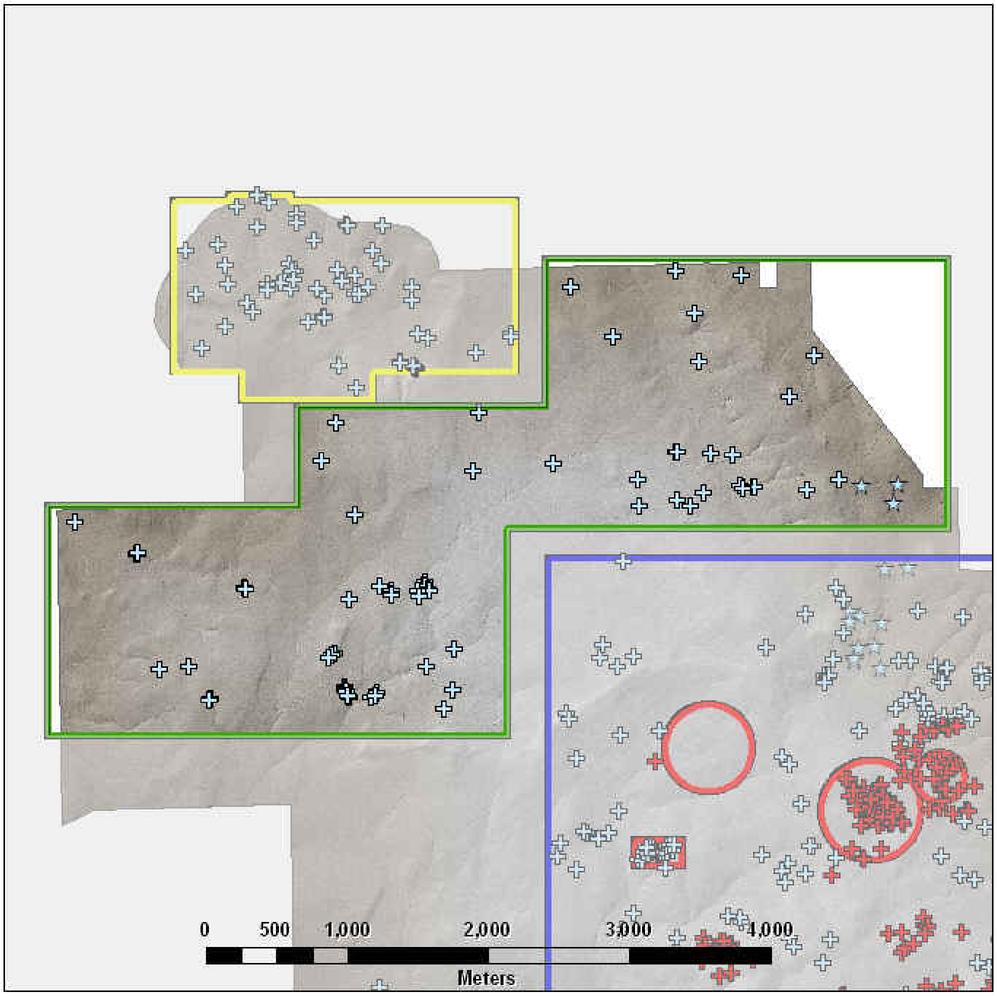
Figure 4-10.1 – Area of Interest 1

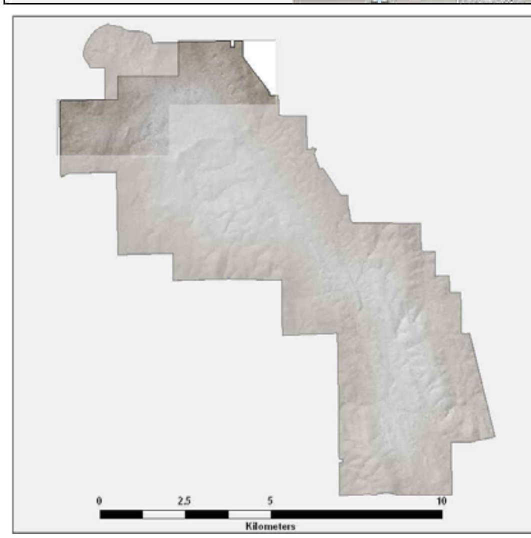




Area of Interest: 1
Original Classification: Potential MEC Features.
Original classification based on: large numbers of crater-shaped depressions.
CSM targets: None
Field Visit: Not visited; no site access.
Revised classification: Other Features of Interest
Revised classification based on:
No CSM targets
Depressions are larger than typical ordnance craters
Depressions are relatively scattered
Confidence level: Medium, no field visit

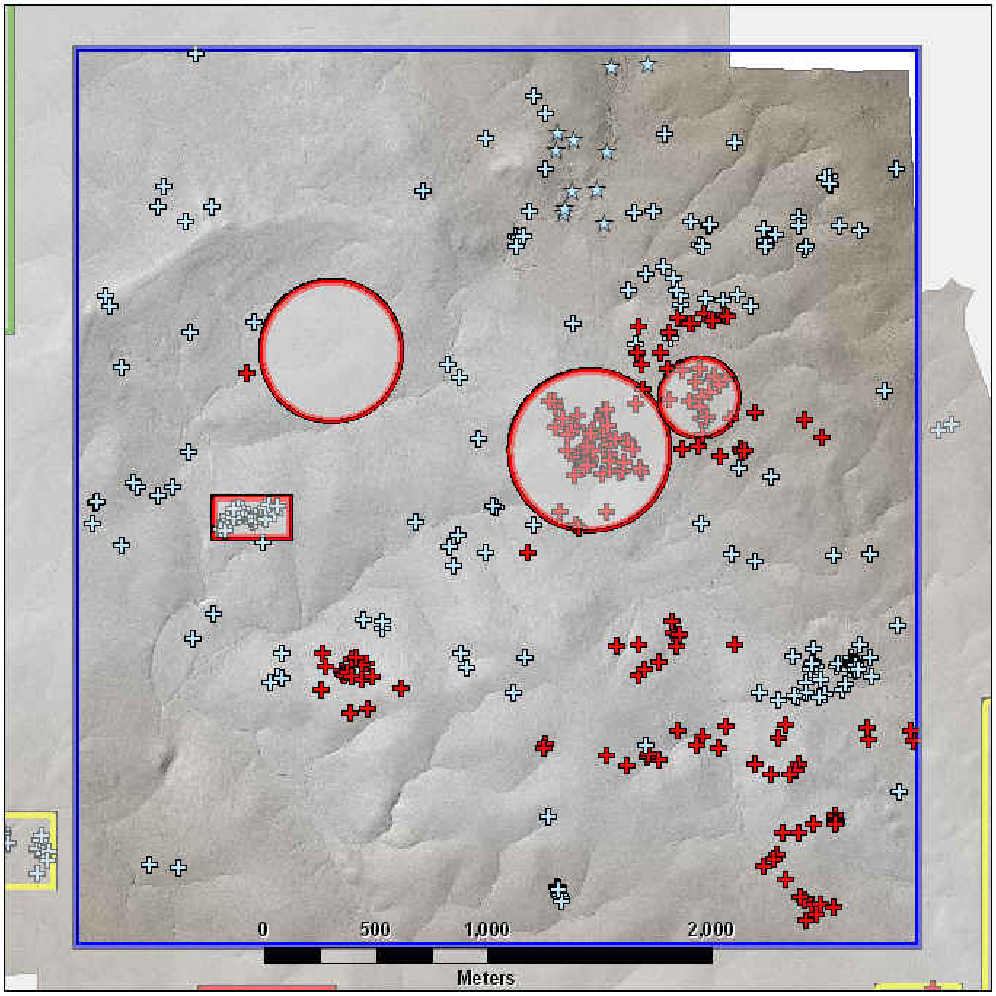
Figure 4-10.2 – Area of Interest 2

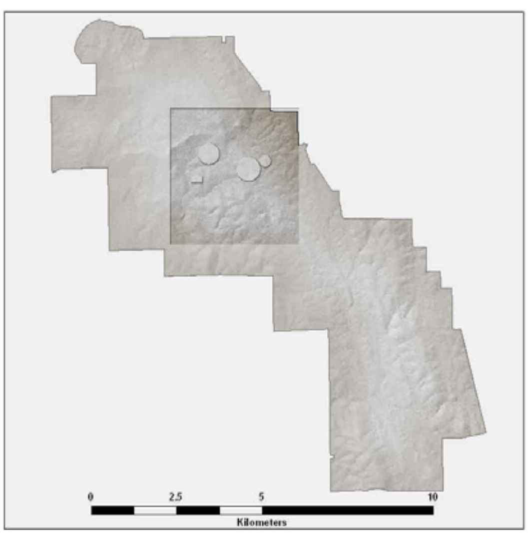




Area of Interest: 2
Original Classification: Other Features of Interest
Original Classification based on: depressions evident but scattered and with no apparent patterns
CSM targets: Night Bombing Target No. 2 (1956/9)
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on: No documented use of most CSM targets. Depressions are larger than typical ordnance craters. Depressions are often not circular. Depressions are relatively scattered.
Confidence level: Medium, no field visit

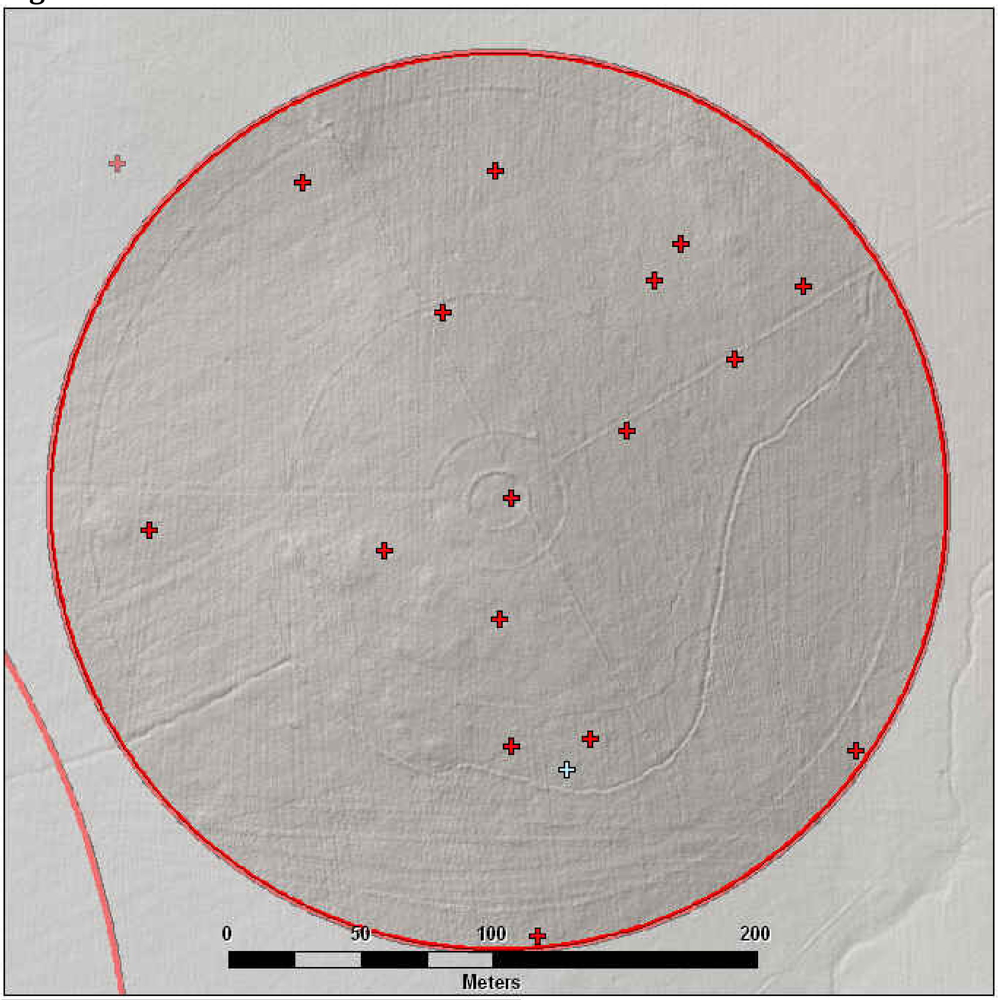
Figure 4-10.3 – Area of Interest 3

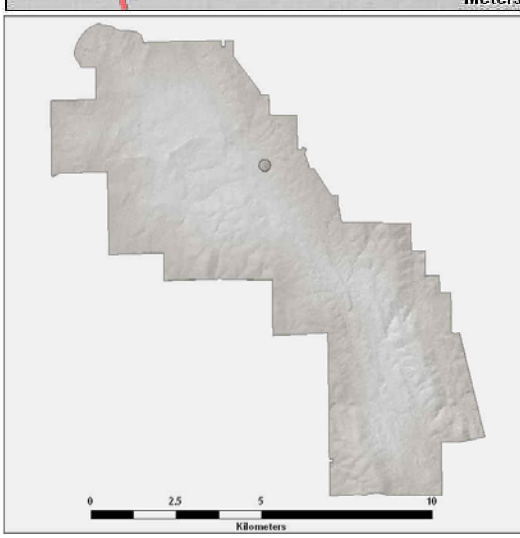




Area of Interest: 3
Original Classification: High Potential of MEC Features
Original Classification based on: large numbers of crater-like depressions in close proximity to obvious targets.
CSM targets: Range 2 (1955), Bombing Targets Nos. 2 & 3 (1955/9), Night Bombing Target No. 2 (1956), Target No. 6 (1956/9), Navy Bombing Target T-63 (1956)
Field Visit: Not visited; no site access
Revised classification: High Potential of MEC Features
Revised classification based on: Documented use of most CSM targets . Many depressions have size and shape consistent with ordnance craters, others do not.
Confidence level: Medium, no field visit. In particular, assessment of some individual depressions is sufficiently ambiguous to warrant further validation.

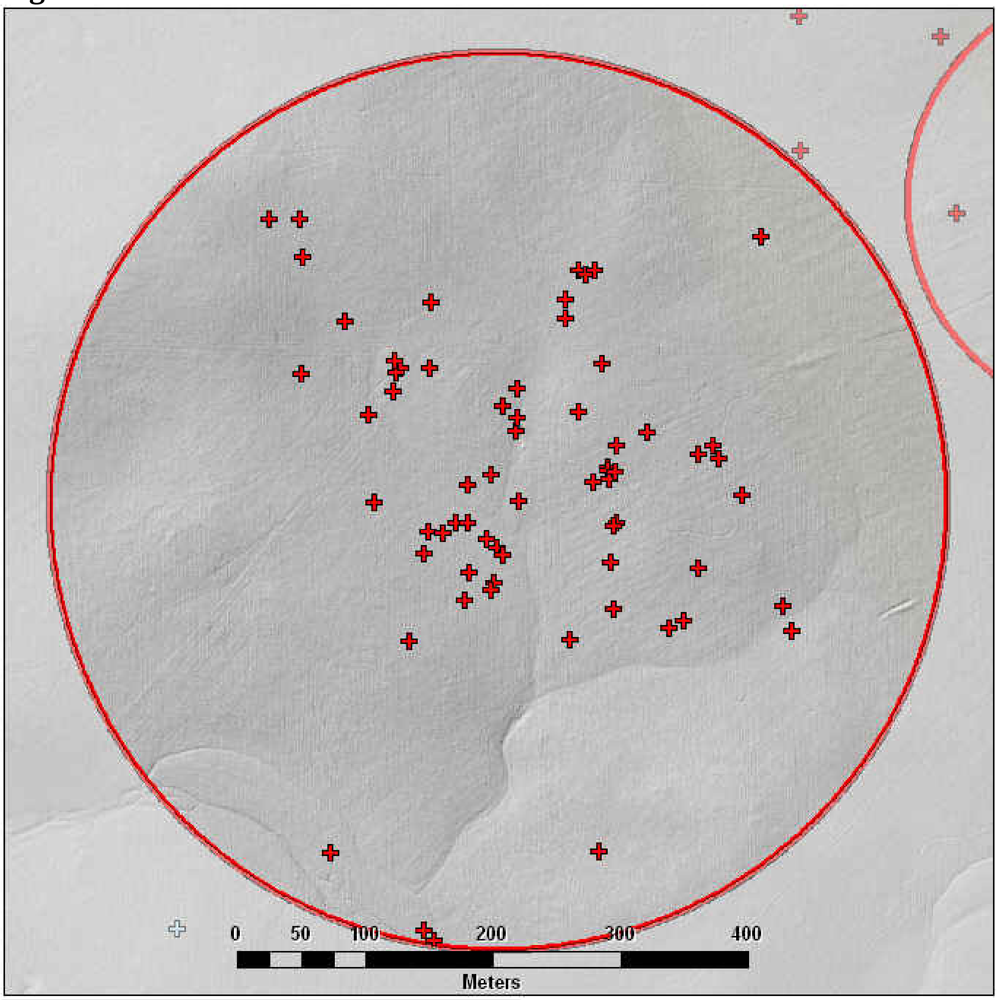
Figure 4-10.4 – Area of Interest 4

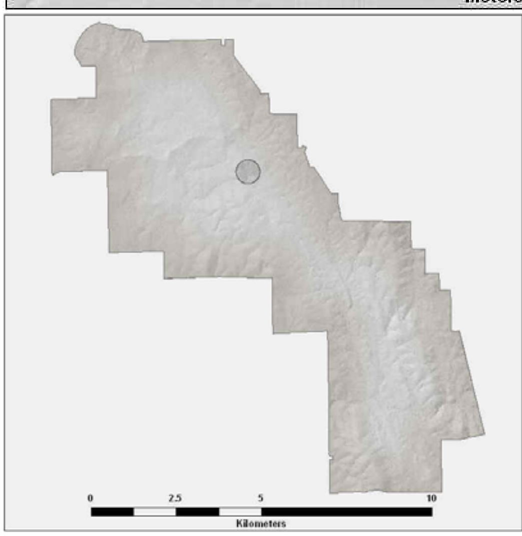




Area of Interest: 4. This is Potential Bombing Area 1.
Original Classification: Likely MEC Features
Original Classification based on: Numerous crater-like depressions within apparent target rings centered on small mound in the center of the rings
CSM targets: Range 2 (1955), Range 8 (1956)
Field Visit: Not visited; no site access
Revised classification: Likely MEC Features
Revised classification based on: Depressions have sizes and shapes consistent with ordnance use. Depressions are associated with target rings. Although the target rings are outside of the mapped areas for ranges with HE use the feature is clearly a bombing target
Confidence level: High

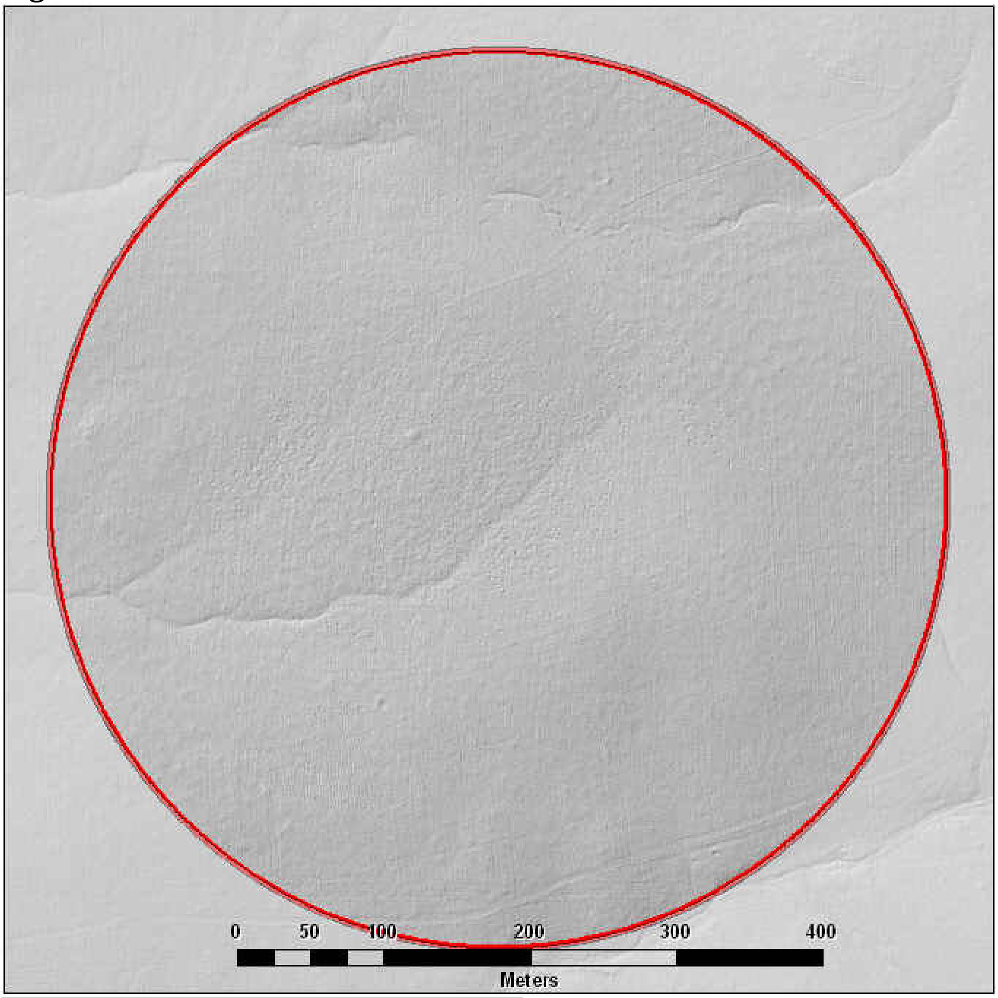
Figure 4-10.5 – Area of Interest 5

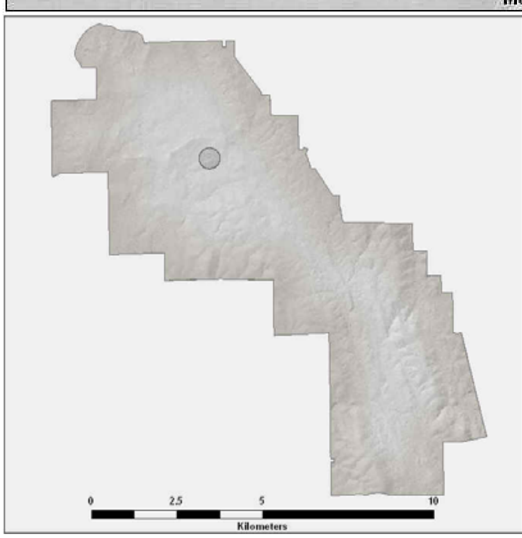




Area of Interest: 5. This is Potential Bombing Area 2
Original Classification: Likely MEC Features
Original Classification based on: large numbers of crater-shaped depressions relatively clustered.
CSM targets: Range 2 (1955), Bombing Target 3 (1955), Range 8 (1956), Target No. 6 (1956/9)
Field Visit: Not visited; no site access
Revised classification: Likely MEC Features
Revised classification based on: Depressions have sizes and shapes consistent with ordnance use. Depressions are highly clustered in a pattern consistent with bombing practice. Depressions are located in CSM Bombing Target 3 which had documented HE use.
Confidence level: High

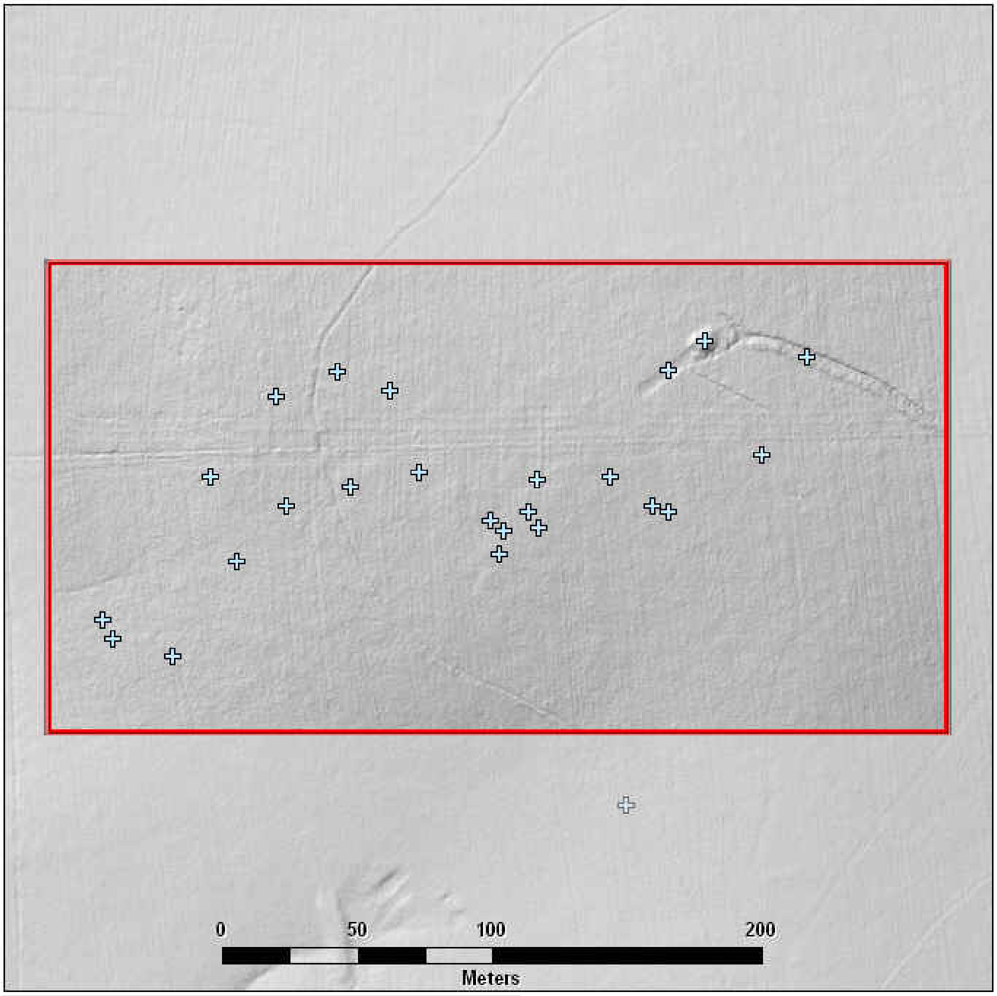
Figure 4-10.6 – Area of Interest 6

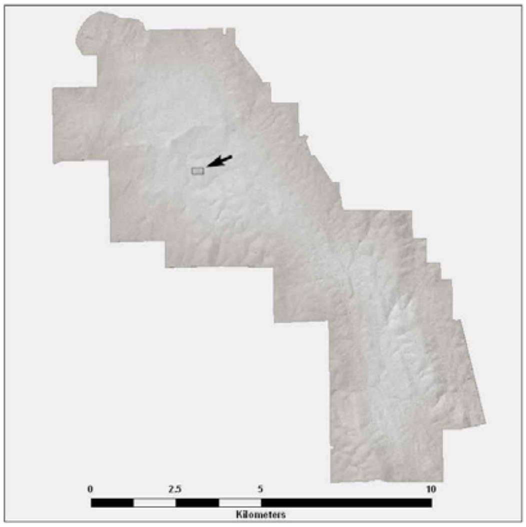




Area of Interest: 6. This is Potential Bombing Area 3
Original Classification: Likely MEC Features
Original Classification based on: large numbers of crater-shaped depressions relatively clustered.
CSM targets: Range 2 (1955), Bombing Target 3 (1955), Target No. 6 (1956/9)
Field Visit: Not visited; no site access
Revised classification: Likely MEC Features
Revised classification based on: Depressions have sizes and shapes consistent with ordnance use. Depressions are highly clustered in a pattern consistent with bombing practice. Depressions are located in CSM Bombing Target 3 which had documented HE use.
Confidence level: High

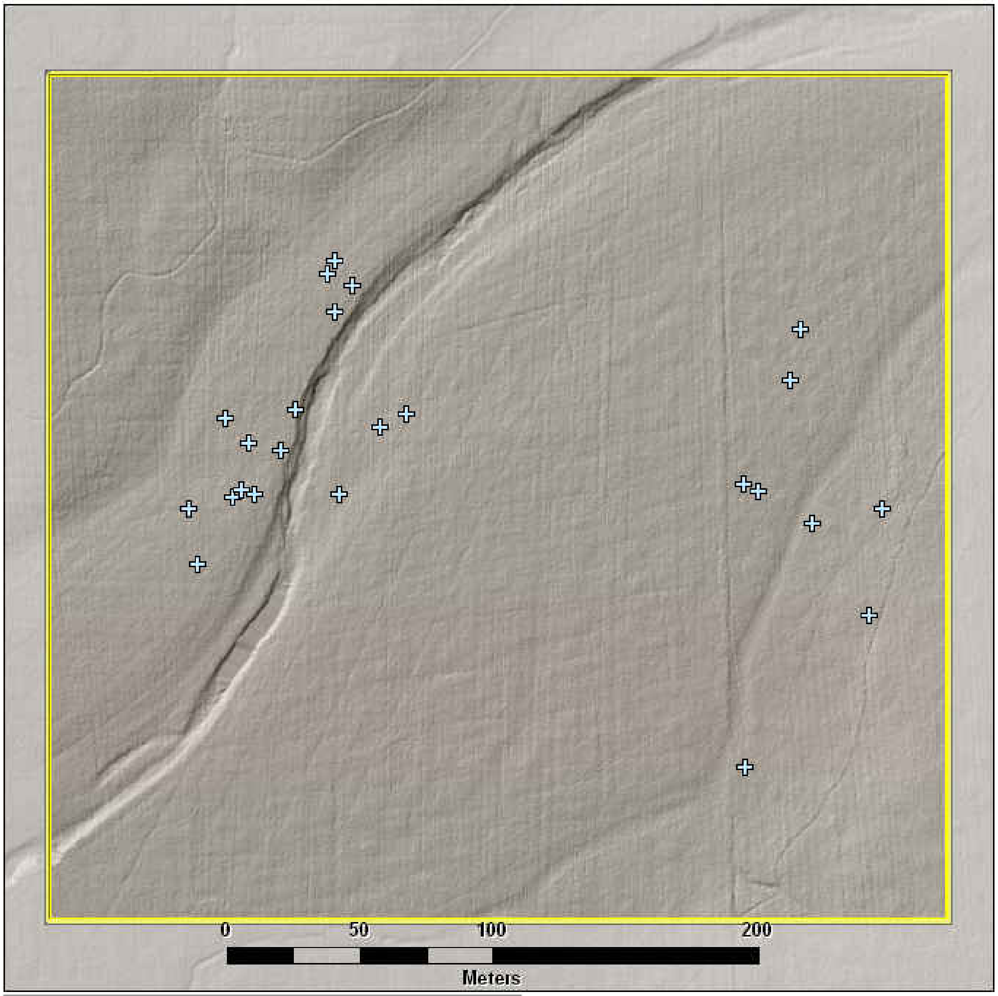
Figure 4-10.7 – Area of Interest 7

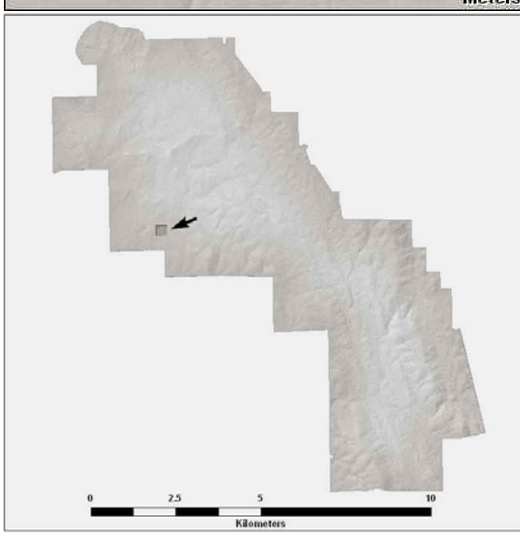




Area of Interest: 7
Original Classification: Likely MEC Features
Original Classification based on: large number of crated-shaped depressions, relatively clustered
CSM targets: Bombing Targets Nos. 2 & 3 (1955), Night Bombing Target No. 2 (1956), Bombing Target No. 6 (1956)
Field Visit: Not visited; no site access
Revised classification: Potential MEC Features
Revised classification based on: Depressions are not always circular, and are not in a pattern typical of bombing practice or OB/OD use, nor are they near obvious roads. Depressions are close to AOI 6, a potential bombing target.
Confidence level: Medium, no field visit. This area is still ambiguous and warrants additional validation.

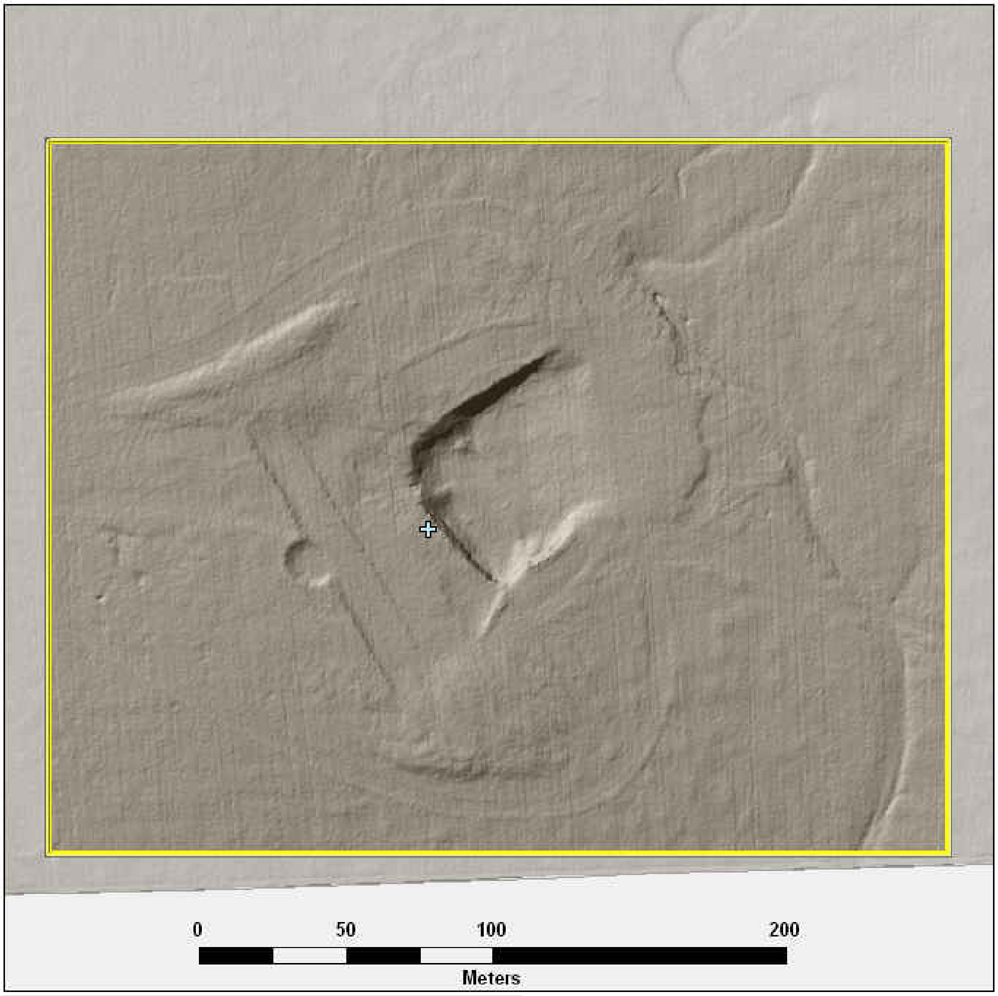
Figure 4-10.8 – Area of Interest 8

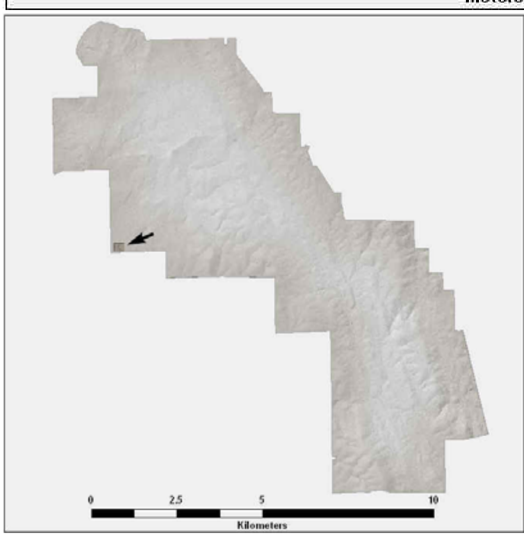




Area of Interest: 8
Original Classification: Potential MEC Features
Original Classification based on: Two closely spaced groups of depressions
CSM targets: Primary Toss Bomb target (1956) (No evidence of actual use)
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on: Depressions are not clustered in a manner consistent with bombing practice or OB/OD use, nor are they near obvious roads. No correlation with CSM targets.
Confidence level: Medium, no field visit. This area is still ambiguous and warrants additional validation.

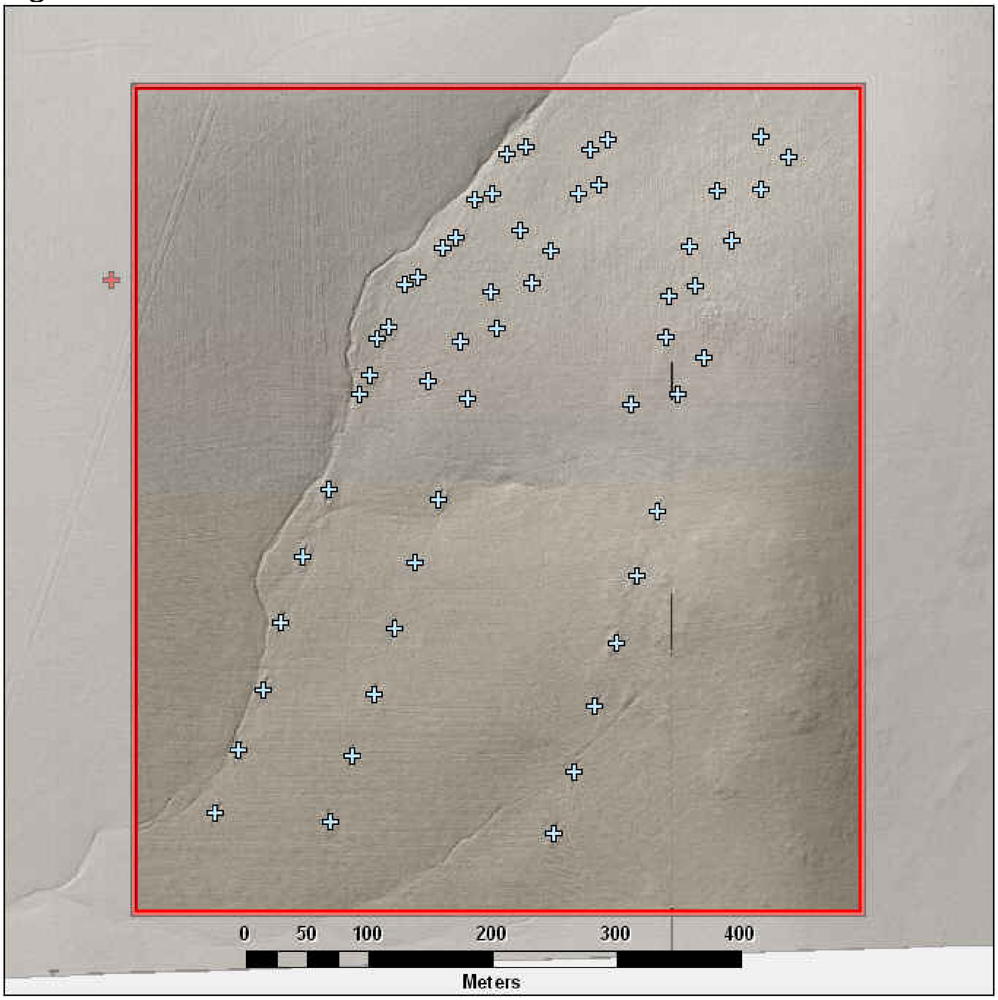
Figure 4-10.9 – Area of Interest 9

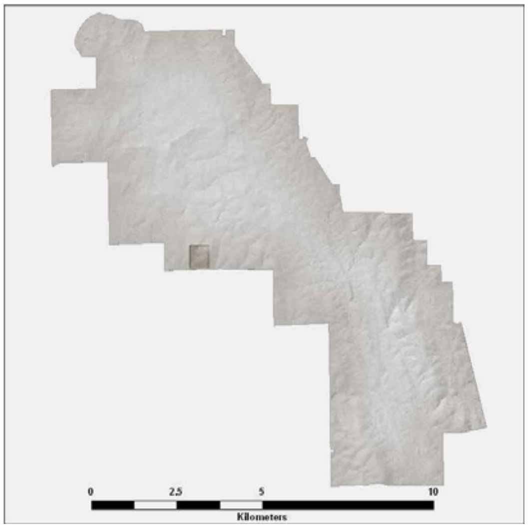




Area of Interest: 9
Original Classification: Potential MEC Features
Original Classification based on: Ground surface feature representing a potential firing point
CSM targets: Primary Toss Bomb target (1956) (No evidence of actual use)
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on:
The feature does not resemble a gun emplacement and appears to be more consistent with sand and gravel mining
Confidence level: Medium, no field visit

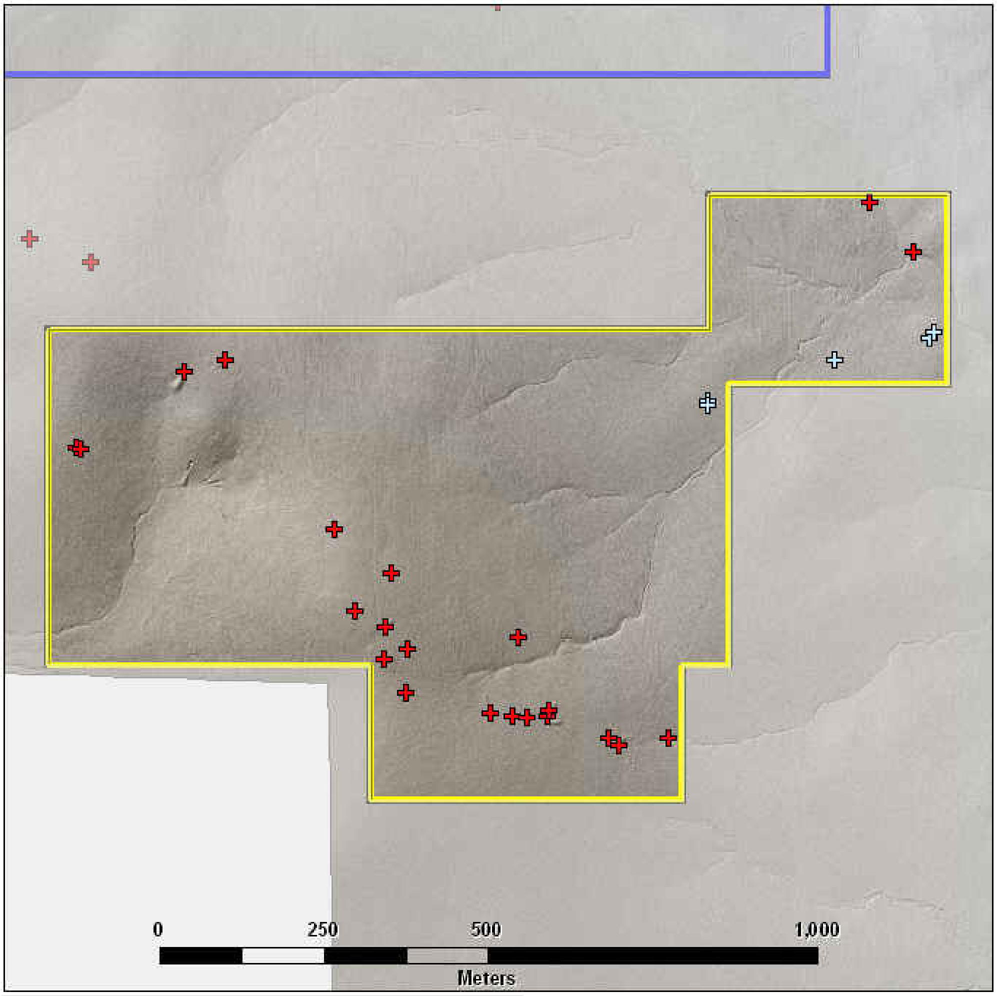
Figure 4-10.10 – Area of Interest 10

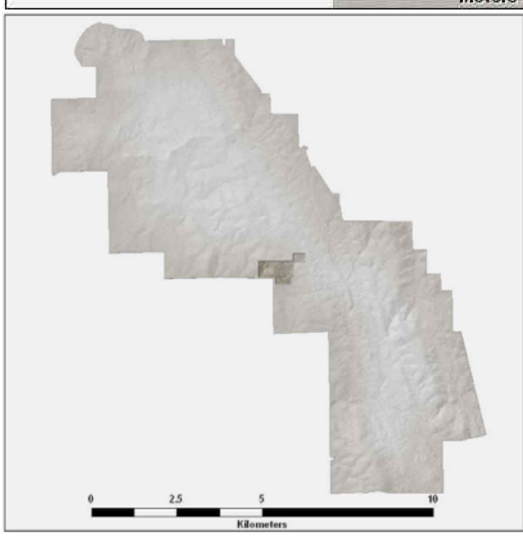




Area of Interest: 10
Original Classification: Likely MEC Features
Original Classification based on: Regularly space groups of potential craters
CSM targets: No HE bombing targets
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on: Depressions are clustered in a manner that is not consistent with ordnance use and appear more consistent with mining exploration. Depressions are not near obvious roads as would be expected with OB/OD use
Confidence level: Medium, no field visit. This area is still ambiguous and warrants additional validation.

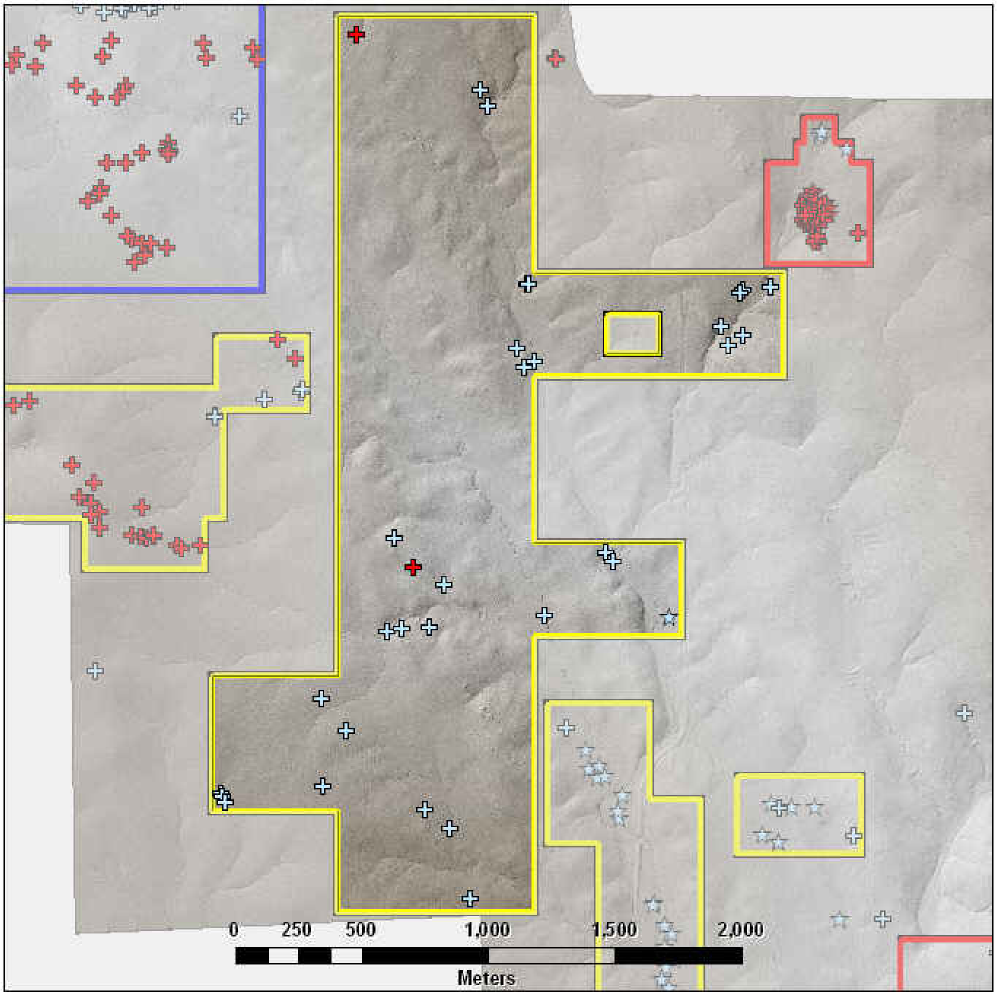
Figure 4-10.11 – Area of Interest 11

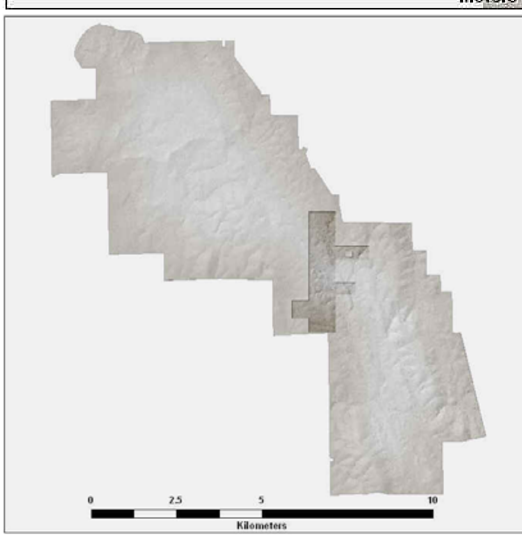




Area of Interest: 11
Original Classification: Potential MEC Features
Original Classification based on: Presence or crater-like depressions following a mostly linear pattern
CSM targets: Ranges 2 & 4 (1955)
Field Visit: Not visited; no site access
Revised classification: Likely MEC Features
Revised classification based on: Many of the depressions have shapes and sizes consistent with ordnance use..
However, CSM targets did not include HE use.
Confidence level: Medium, no field visit. This area is still ambiguous and warrants additional validation.

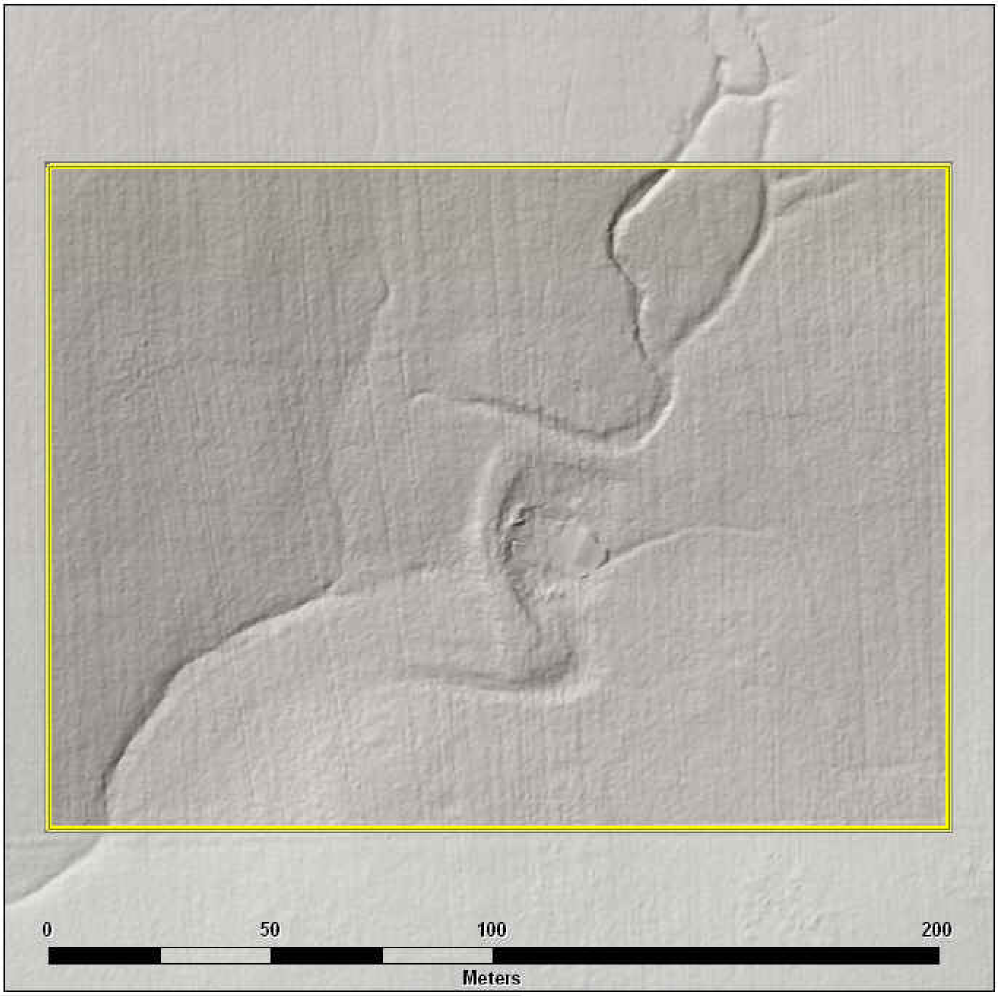
Figure 4-10.12 – Area of Interest 12

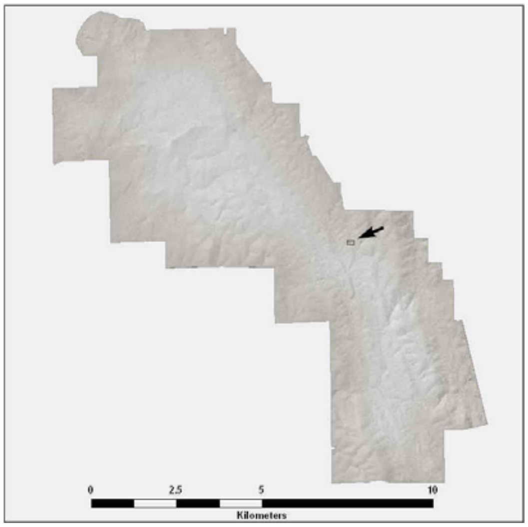




Area of Interest: 12
Original Classification: Potential MEC Features
Original Classification based on: Presence of a number of crater-like depressions
CSM targets: No HE bombing targets
Field Visit: Not visited; no site access
Revised classification: Potential MEC Features
Revised classification based on: Depressions are widely scattered. Most, but not all, depressions have sizes and shapes that are not consistent with ordnance use. CSM targets did not include HE use.
Confidence level: Medium, no field visit. This area is still ambiguous and warrants additional validation.

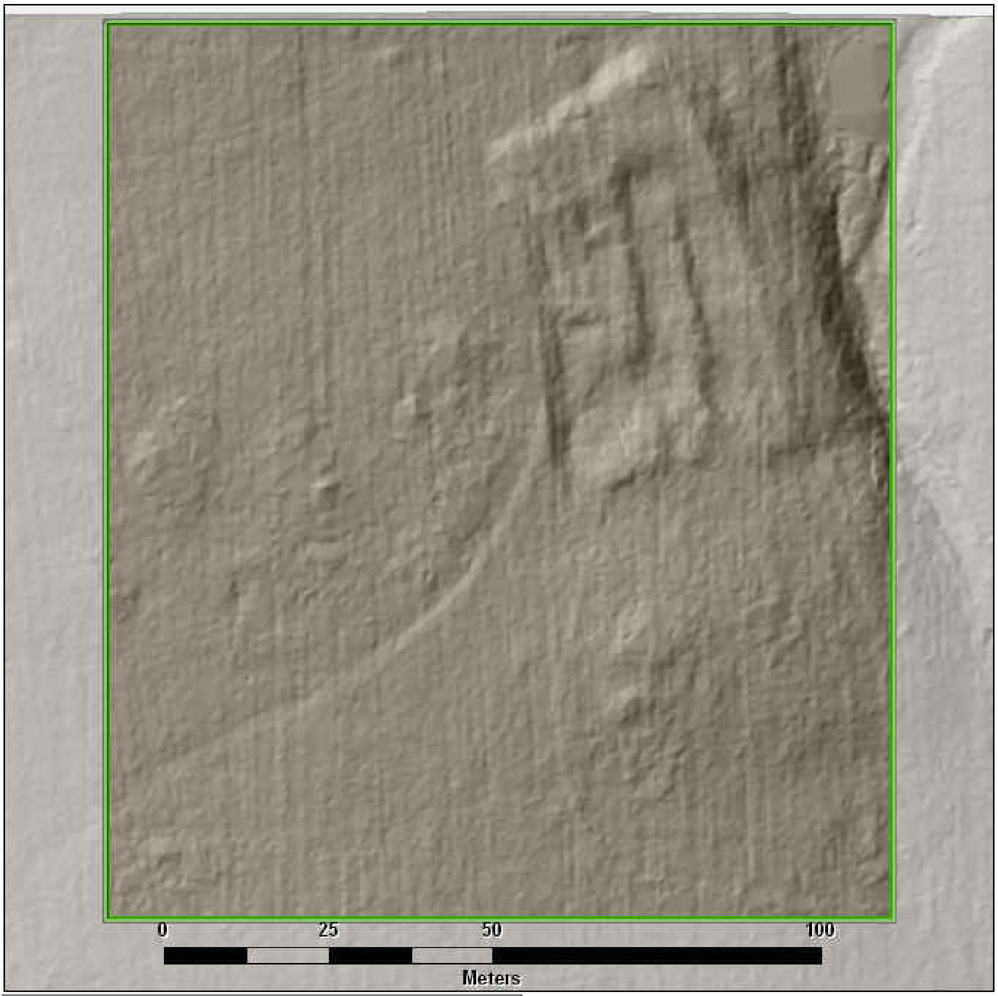
Figure 4-10.13 – Area of Interest 13

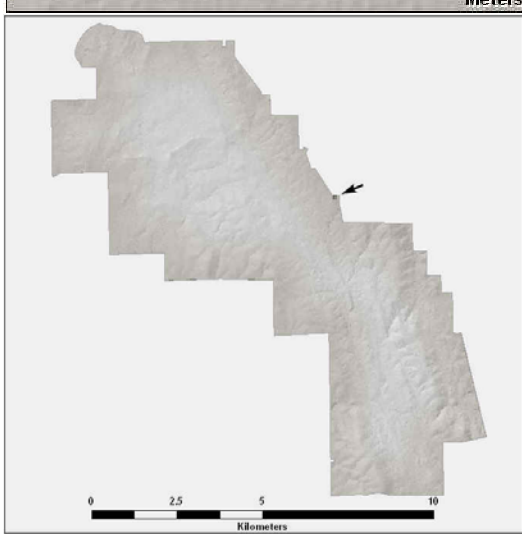




Area of Interest: 13
Original Classification: Potential MEC Features
Original Classification based on: Non-natural surface feature representing a potential firing point.
CSM targets: Range 5 (1955), Ranges 8 & 11 (1956), 57mm Recoilless Rifle/60mm Mortar/.50 Cal. Machine gun range (1959)
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on: The feature does not resemble a gun emplacement and appears to be more consistent with agriculture-related water impoundment.
Confidence level: Medium, no field visit

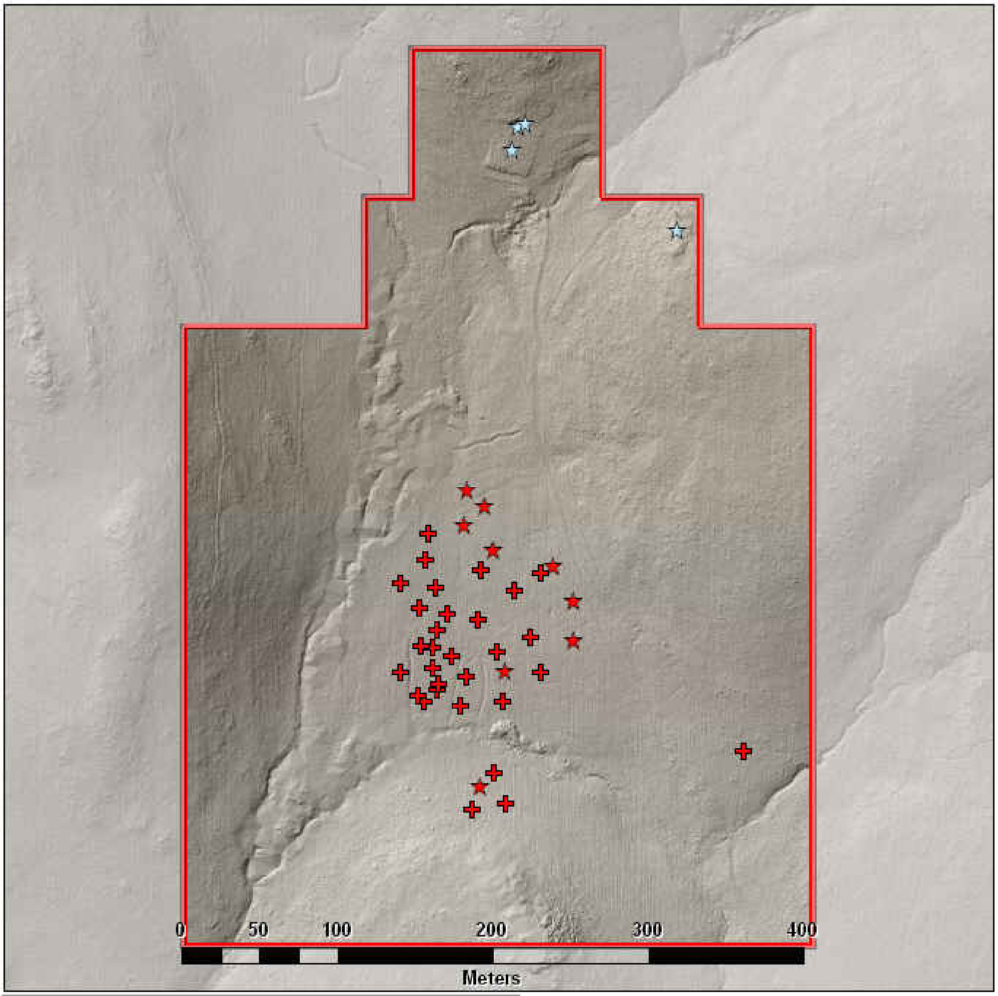
Figure 4-10.14 – Area of Interest 14

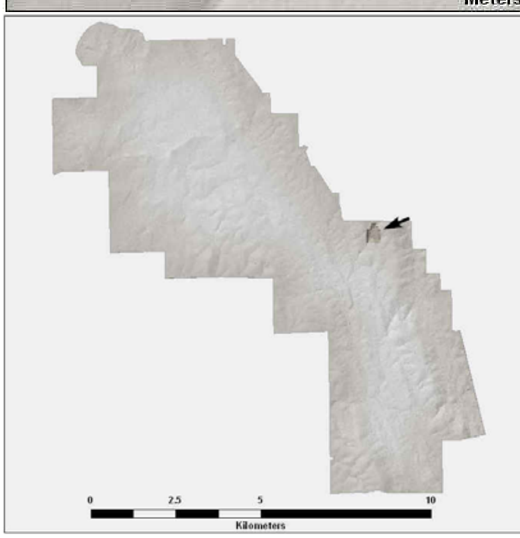




Area of Interest: 14
Original Classification: Other Features of Interest
Original Classification based on: Earthwork partially under trees
CSM targets: Range 8 (1956), 57mm Recoilless Rifle/60mm Mortar/.50 Cal. Machine gun range (1959)
Field Visit: Not visited; no site access
Revised classification: Other Features of Interest
Revised classification based on: Feature appears to be more consistent with agriculture or mining.
Confidence level: Medium, no field visit

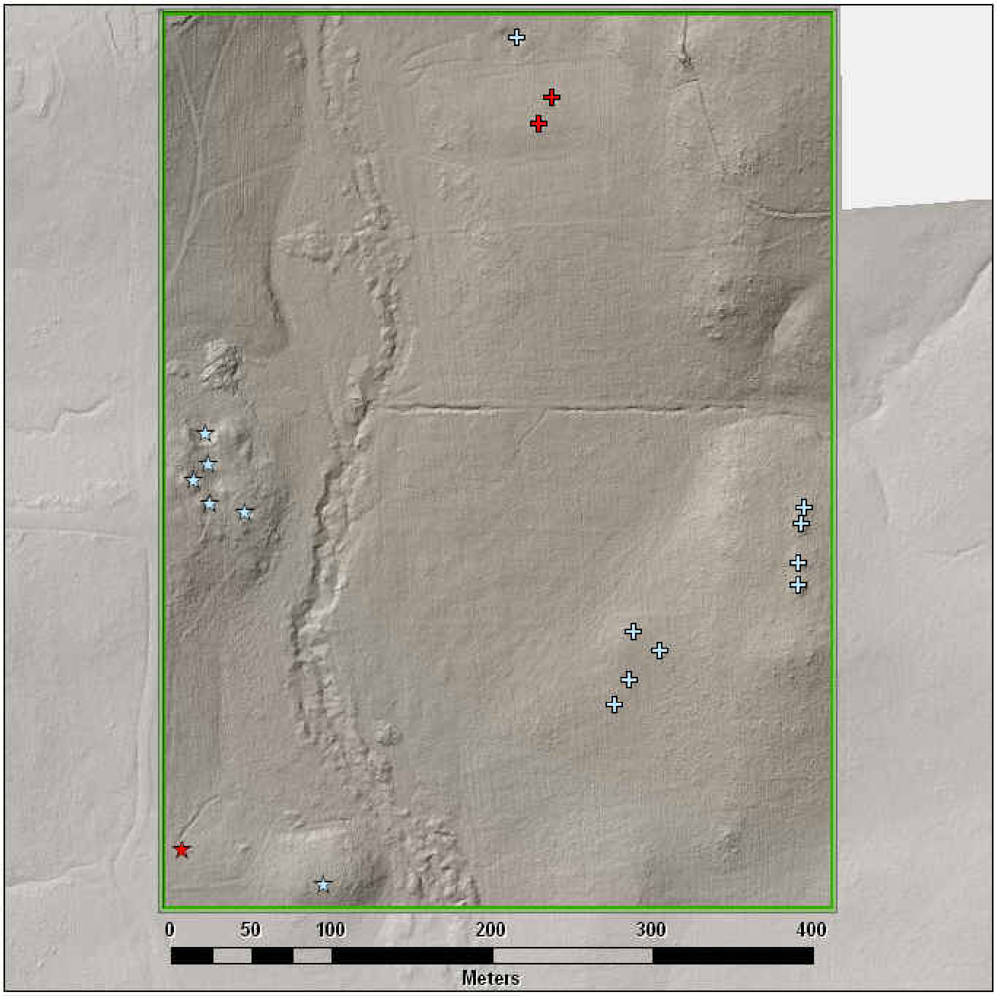
Figure 4-10.15 – Area of Interest 15

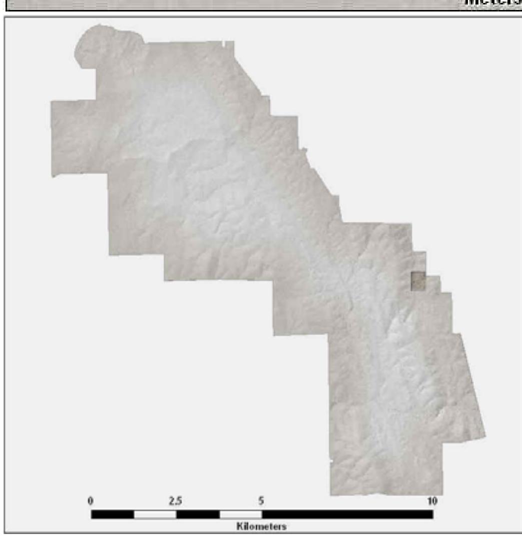




Area of Interest: 15. This is Potential Firing Range 1
Original Classification: Likely MEC features
Original Classification based on: Large number of depressions clustered on and around what appeared to be a simulated ship target scored on the ground surface
CSM targets: Ranges 8 & 11 (1956), 57mm Recoilless Rifle/60mm Mortar/.50 Cal. Machine gun range (1959)
Field Visit: Site was visited
Revised classification: High Potential MEC Features
Revised classification based on: Positive mag results during site visit. Clustering of depressions is consistent with a firing range Presence of apparent target object and flat firing area to the north
Confidence level: High

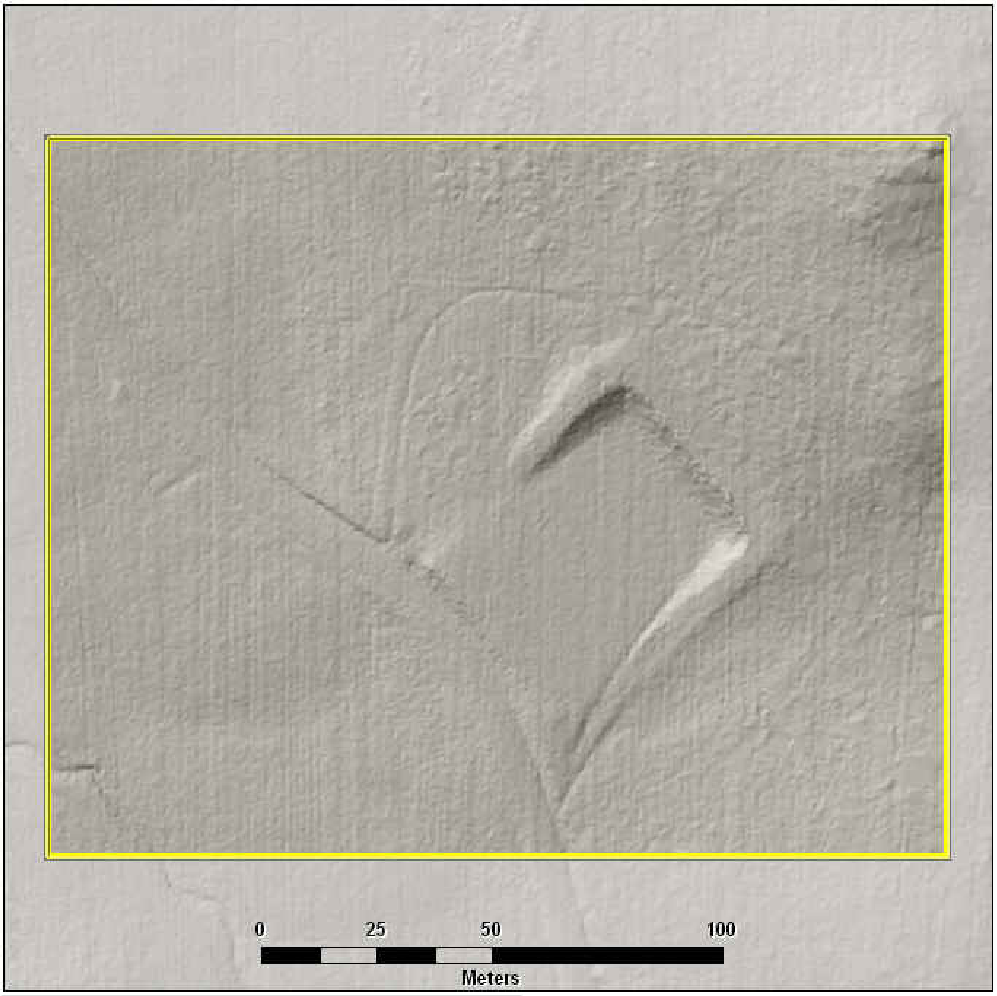
Figure 4-10.16 – Area of Interest 16

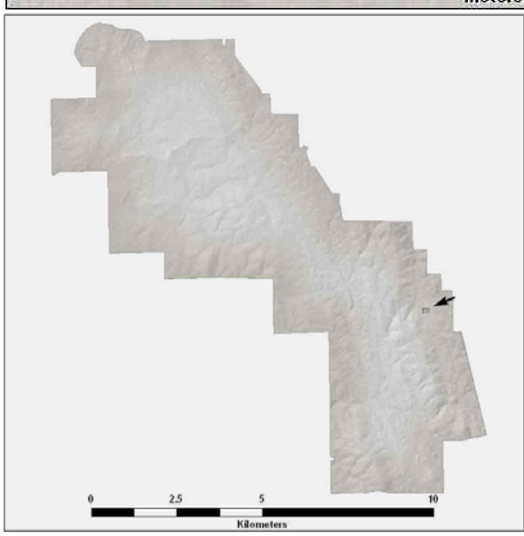




Area of Interest: 16
Original Classification: Other Features of Interest
Original Classification based on: Relatively scarce and random placement of crater-shaped depressions
CSM targets: No HE bombing targets
Field Visit: Part of the site was visited
Revised classification: Potential MEC Features
Revised classification based on: Positive mag response at one of the depressions visited, negative response at others. Depressions not visited are clustered in a manner that is not consistent with bombing practice or OB/OD use, nor are they near obvious roads.
Confidence level: High (for the portions of the site visited, Medium (for the portions not visited). The portion of the site not visited remains ambiguous and warrants further validation.

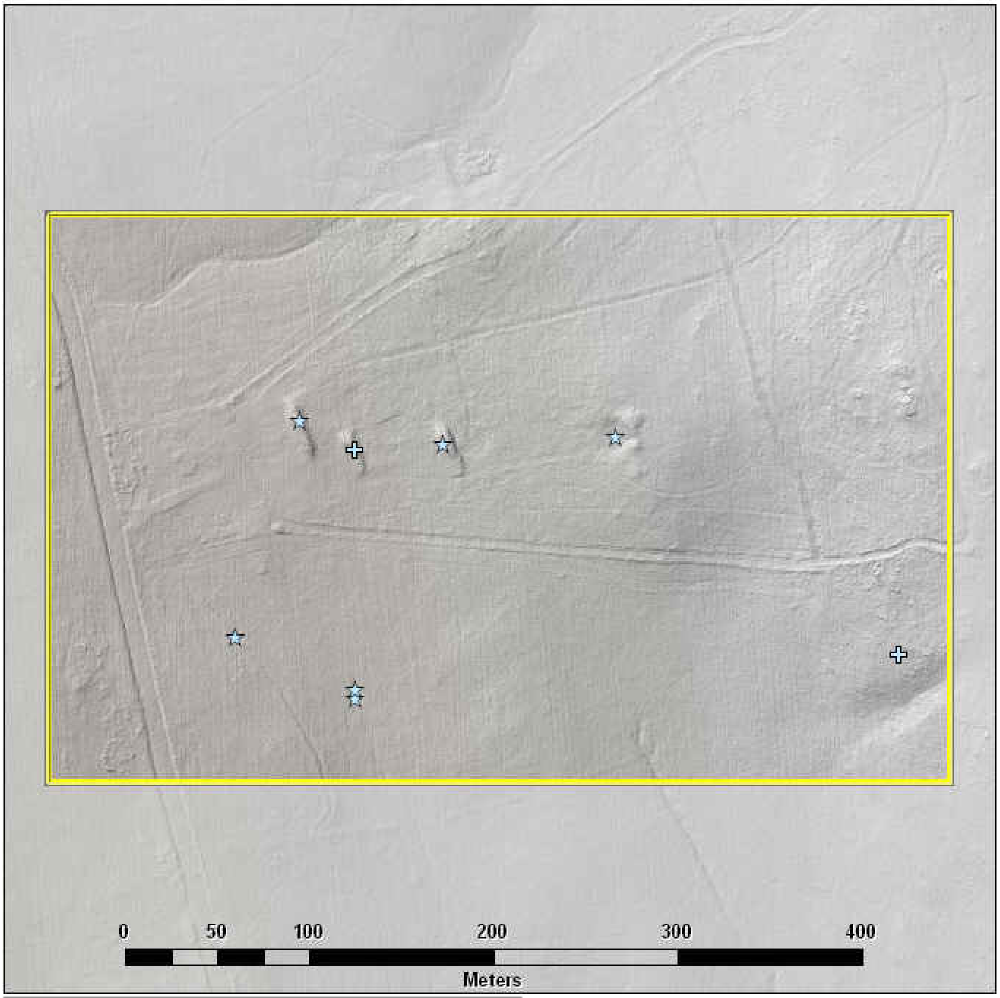
Figure 4-10.17 – Area of Interest 17

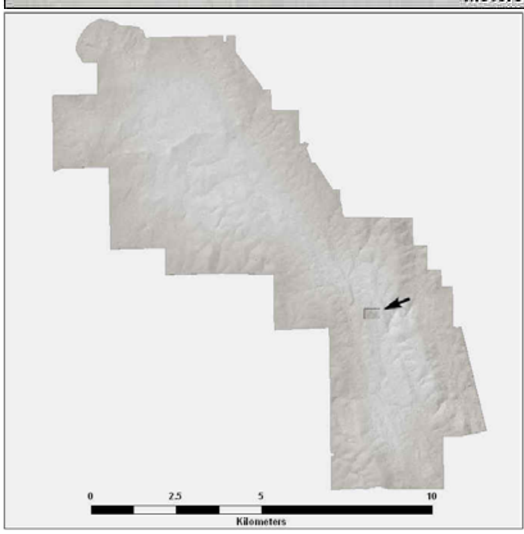




Area of Interest: 17
Original Classification: Potential MEC Features
Original Classification based on: Non-natural surface feature representing a potential firing point.
CSM targets: Range 5 (1955), Proposed Toss Bomb target (1956), Range 11 (1956), USAF I.G. Training Area (1956), Ground to Air Gunnery Range 13 (1959)
Field Visit: Site was not visited
Revised classification: Potential MEC Features
Revised classification based on: The feature does not resemble a gun emplacement and appears, on inspection of the ortho photo, to be a small arms firing range.
Confidence level: Medium, no field visit

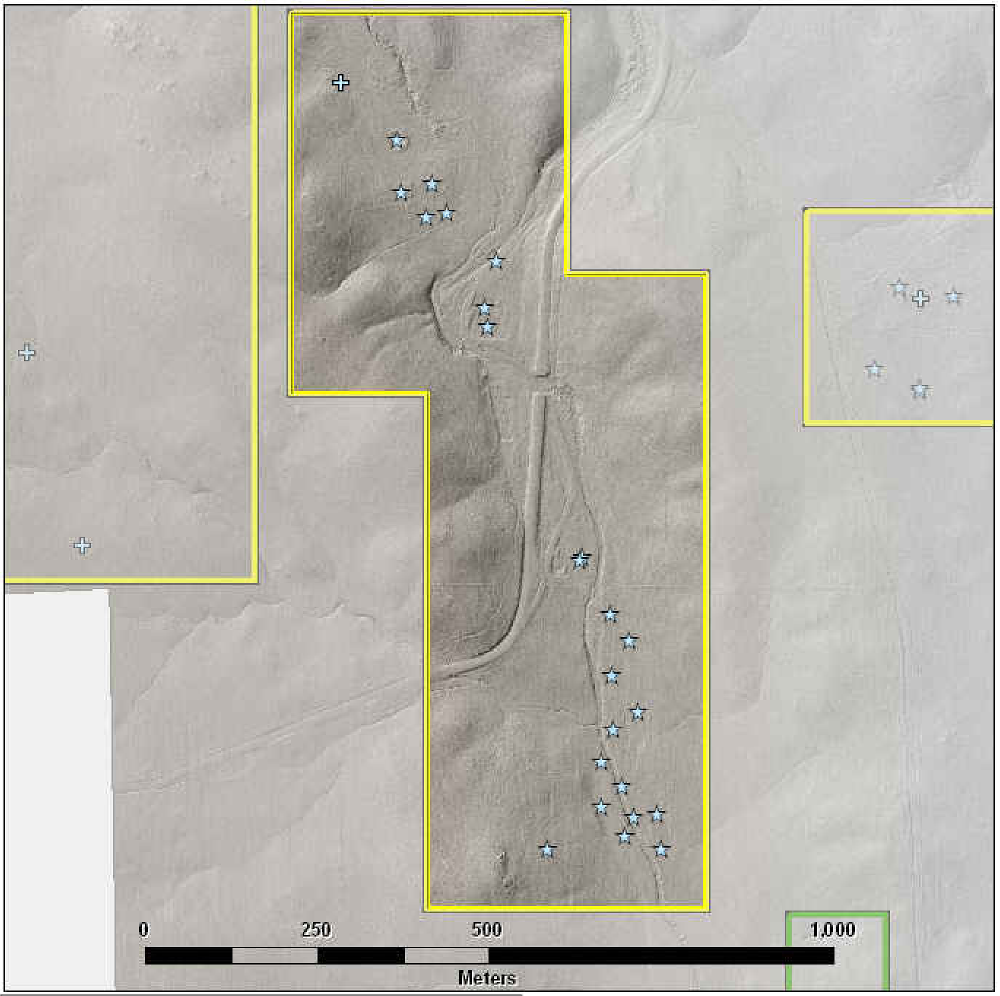
Figure 4-10.18 – Area of Interest 18

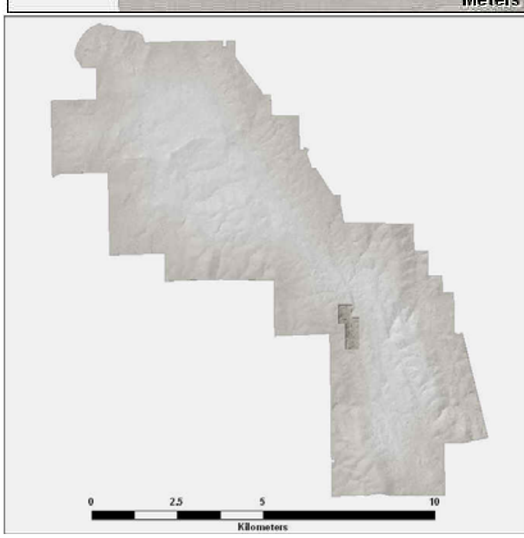




Area of Interest: 18. This is a public pistol firing range.
Original Classification: Potential MEC Features
Original Classification based on: Series of berms thought to part of a training range
CSM targets: Range 5 (1955), Range 11 (1956), USAF I.G. Training Area (1956), .30 Cal. Close Combat Range 11 (1959)
Field Visit: Site was visited
Revised classification: Likely MEC Features
Revised classification based on: Information from USACE site staff was that this was a public target range. Site visit confirmed this use.
Confidence level: High

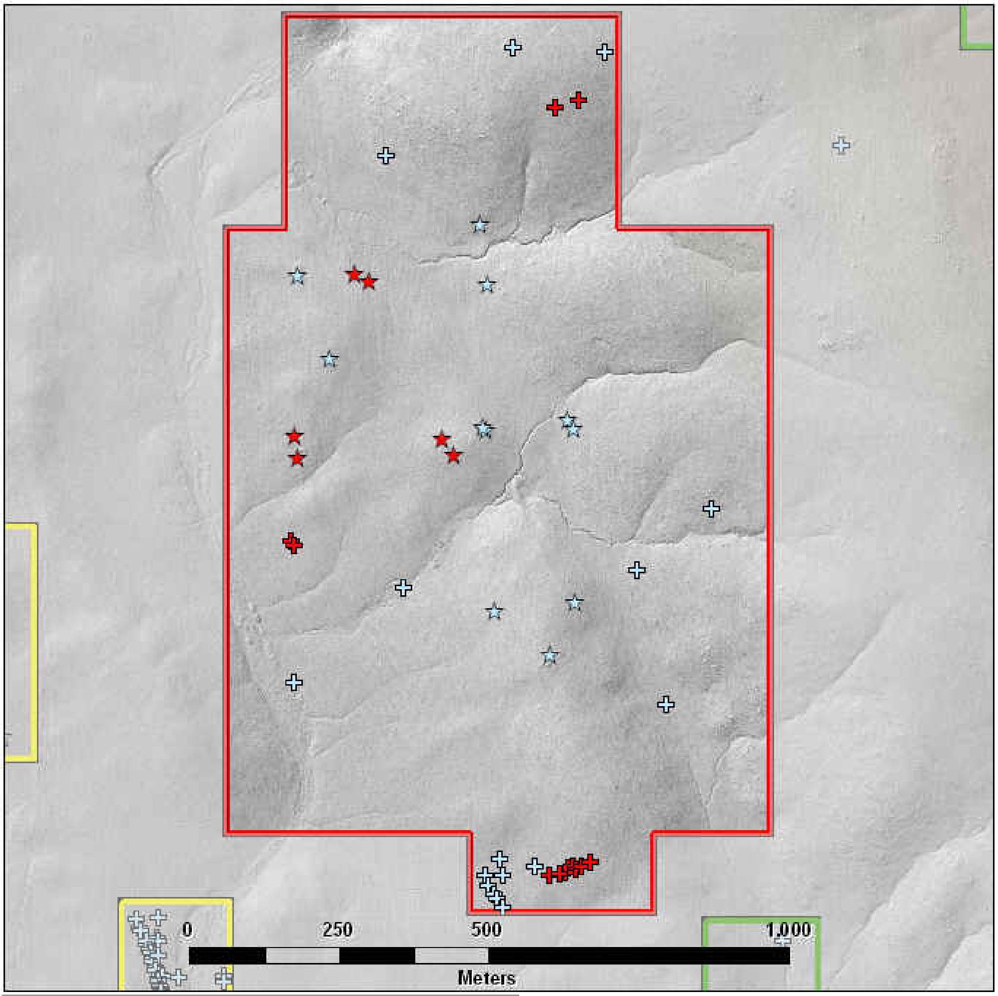
Figure 4-10.19 – Area of Interest 19

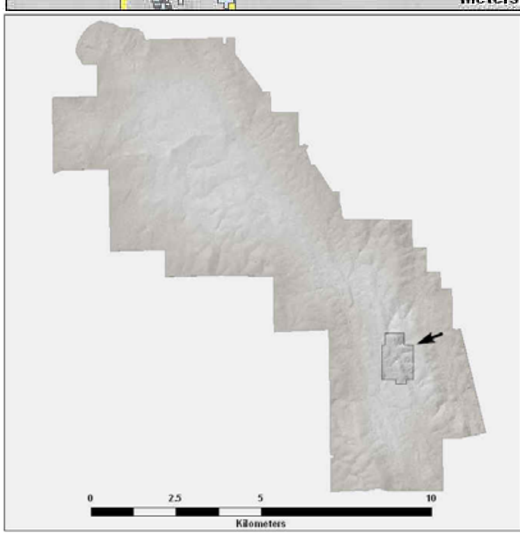




Area of Interest: 19
Original Classification: Potential MEC Features
Original Classification based on: Large number of crater-like depressions arrayed in an essentially linear pattern
CSM targets: Proposed Toss Bomb target (1956) (No evidence of actual use)
Field Visit: Site was visited
Revised classification: Other Features of Interest
Revised classification based on: Negative mag response at all depressions visited.
Confidence level: High

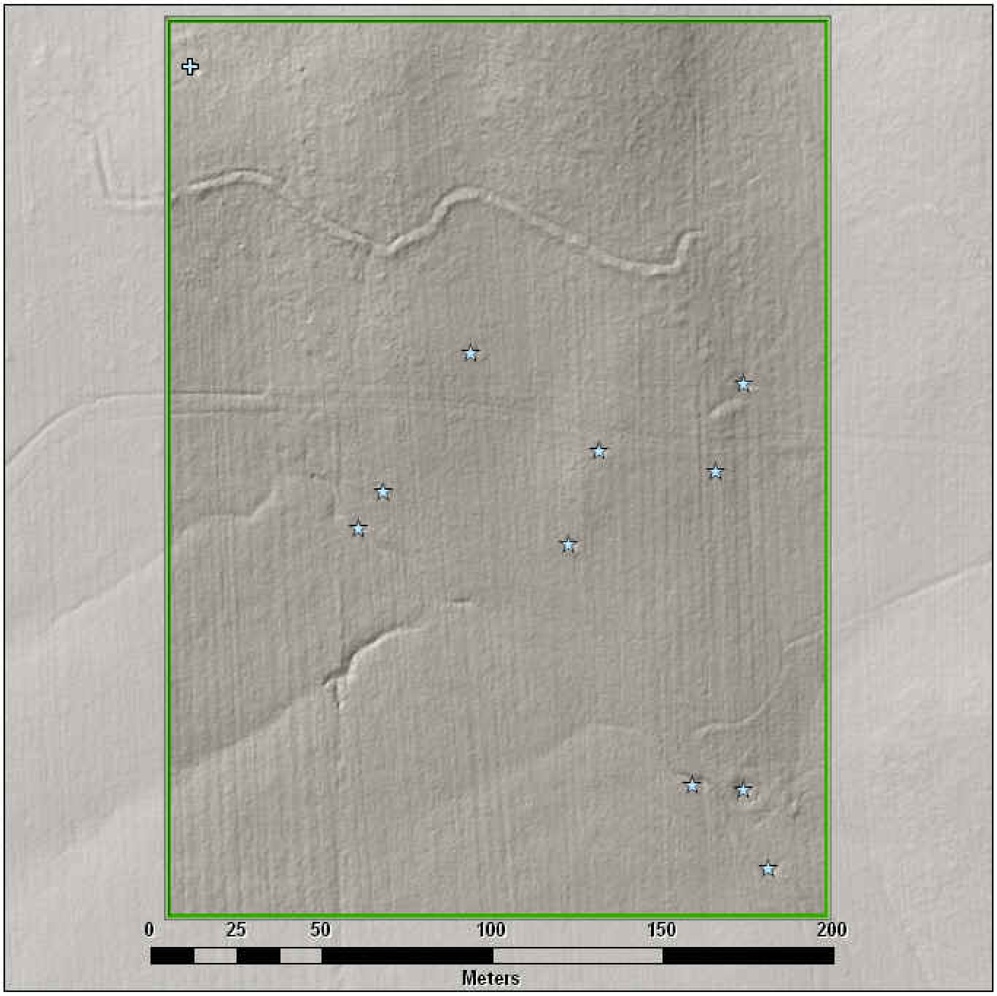
Figure 4-10.20 – Area of Interest 20

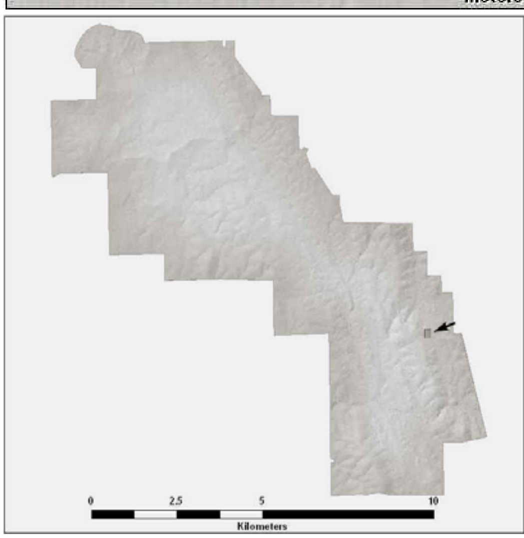




Area of Interest: 20. This is Potential Firing Range 2.
Original Classification: Likely MEC Features
Original Classification based on: The area contains 13 pairs of fan-shaped surface features that resembled potential firing points, and 7 features resembling bunkers
CSM targets: Target 4 (1955), Target No. 2 (1956),.30 Cal. Close Combat Range 11 (1959)
Field Visit: Site was visited
Revised classification: Likely MEC Features
Revised classification based on: Positive mag response at some depressions visited. Site visit identified the fan-shaped surface features as firing points. Presence of bunkers was verified
Confidence level: High

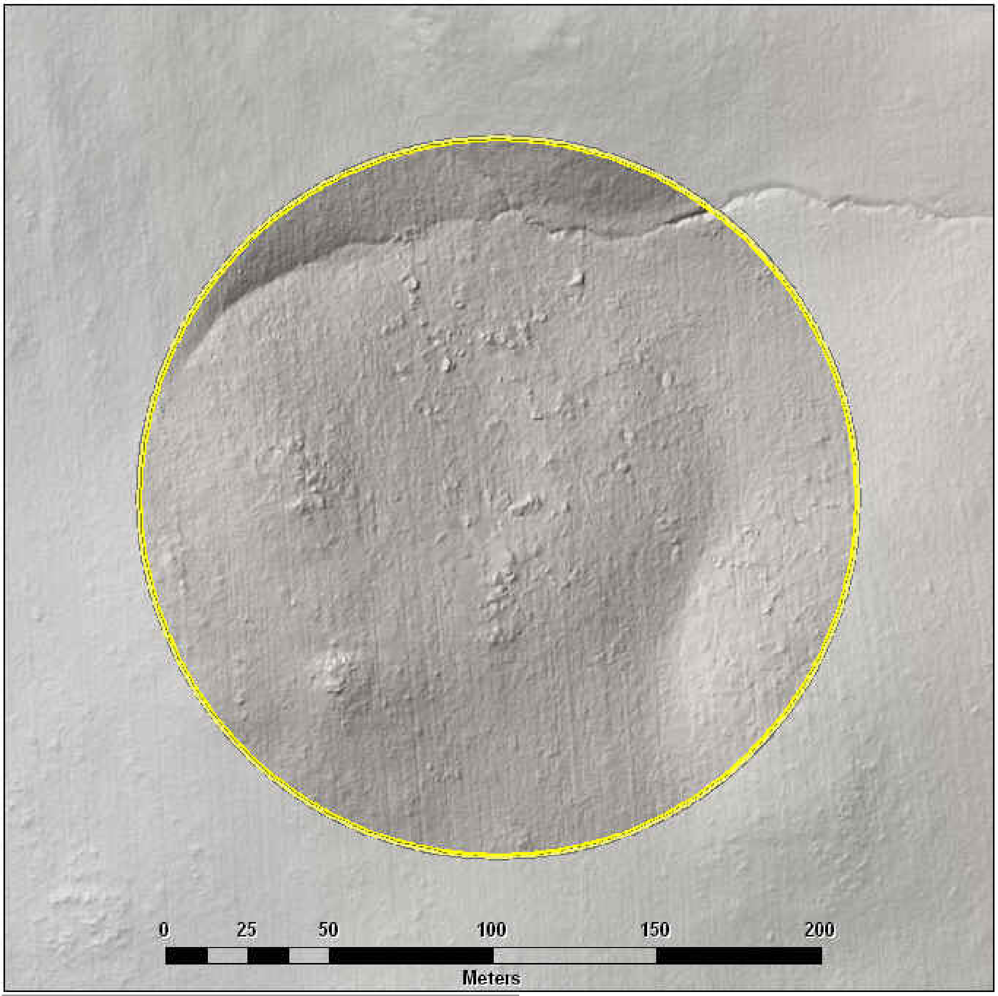
Figure 4-10.21 – Area of Interest 21

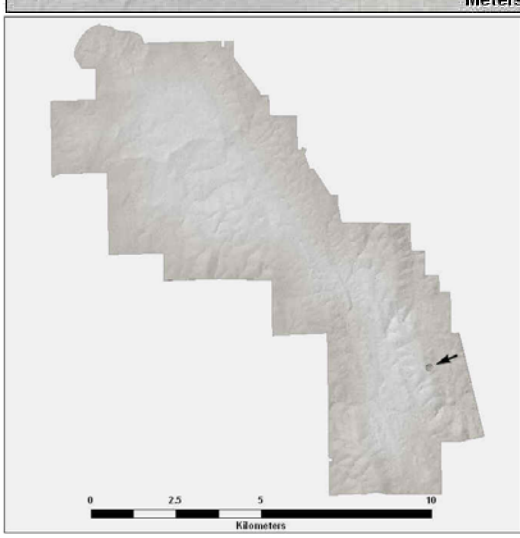




Area of Interest: 21
Original Classification: Other Features of Interest
Original Classification based on: Presence of scattered berms and crater shaped depressions but no distinct patterns
CSM targets: Proposed Toss Bomb (1956) (No evidence of actual use)
Field Visit: Site was visited
Revised classification: Other Features of Interest
Revised classification based on: No mag response at any of the depressions visited. Depressions are scattered in a manner not consistent with ordnance use. Some depressions are not circular.
Confidence level: High

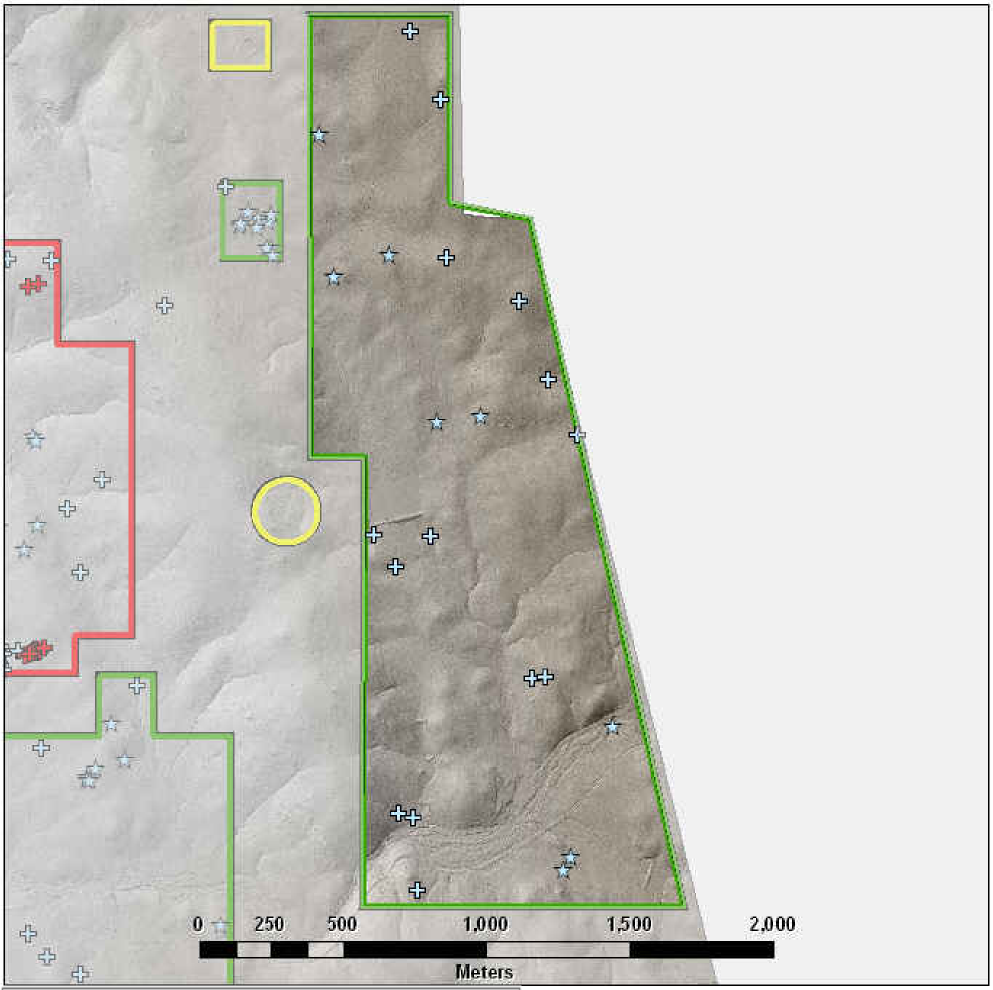
Figure 4-10.22 – Area of Interest 22

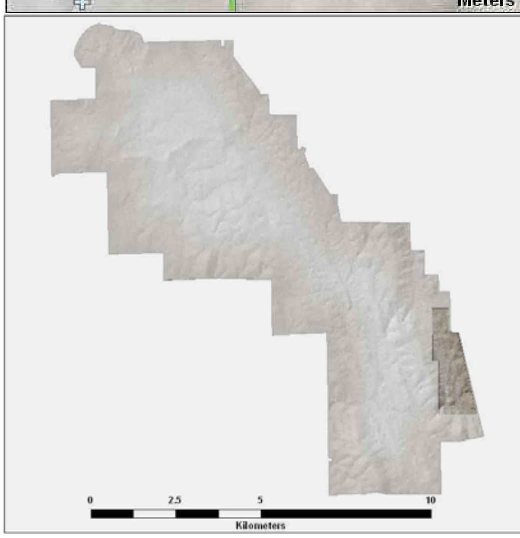




Area of Interest: 22
Original Classification: Potential MEC features
Original Classification based on: Potential shallow cratering under trees
CSM targets: Target No. 2 (1956)
Field Visit: Site was visited
Revised classification: Other features of interest
Revised classification based on: Site visit revealed ground disturbance but no obvious cratering. Surface features may be lidar artifacts of tree coverage and ground debris.
Confidence level: High

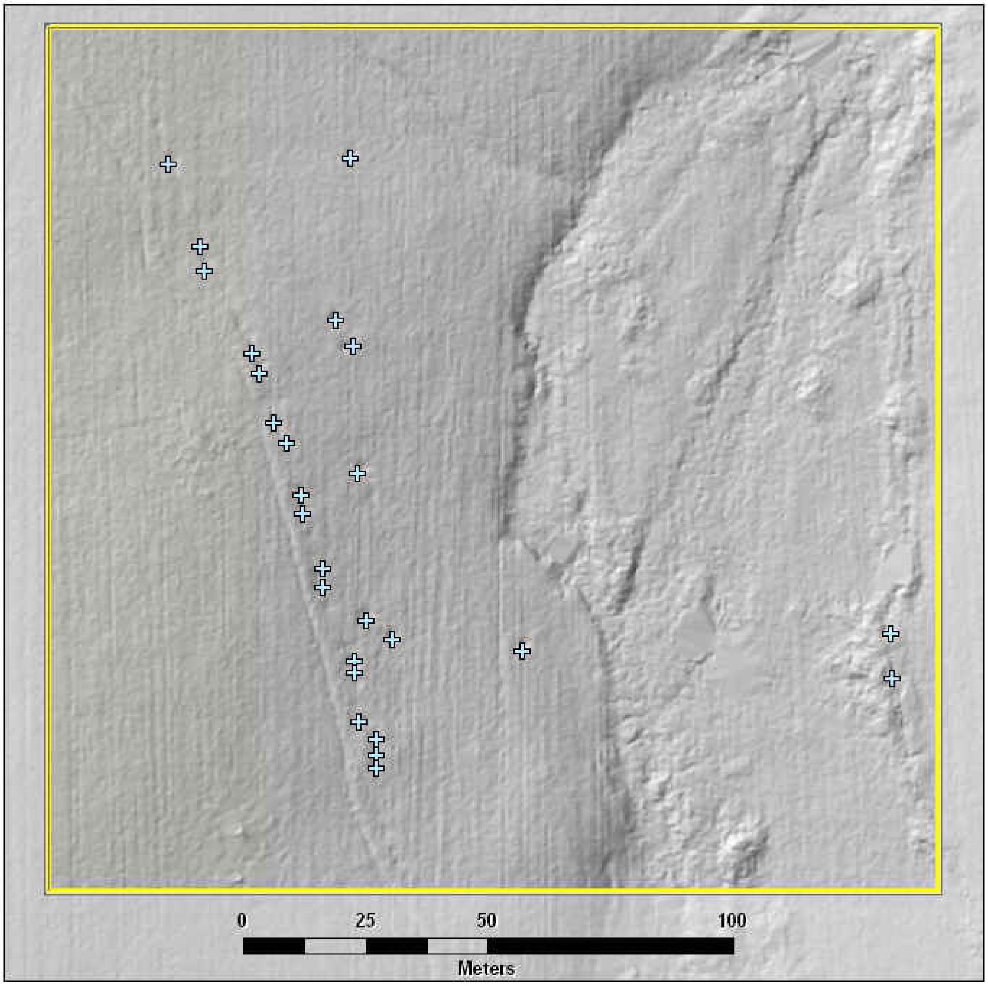
Figure 4-10.23 – Area of Interest 23

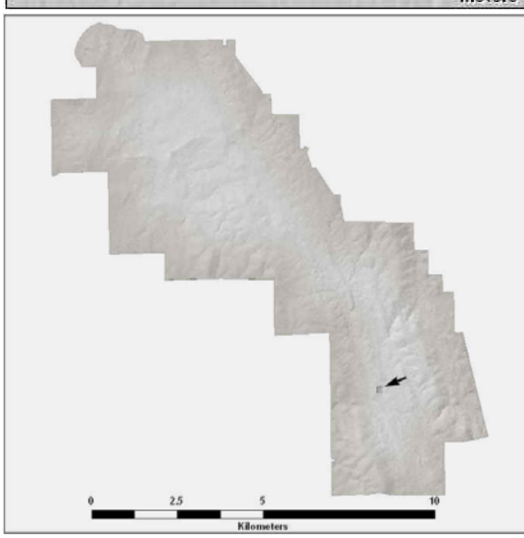




Area of Interest: 23
Original Classification: Other features of interest
Original Classification based on: Scattered depressions, no obvious pattern
CSM targets: Target No.2 (1956)
Field Visit: Site was visited
Revised classification: Other features of interest
Revised classification based on: No mag response at any of the depressions visited. Depressions are scattered in a manner not consistent with ordnance use.
Confidence level: High

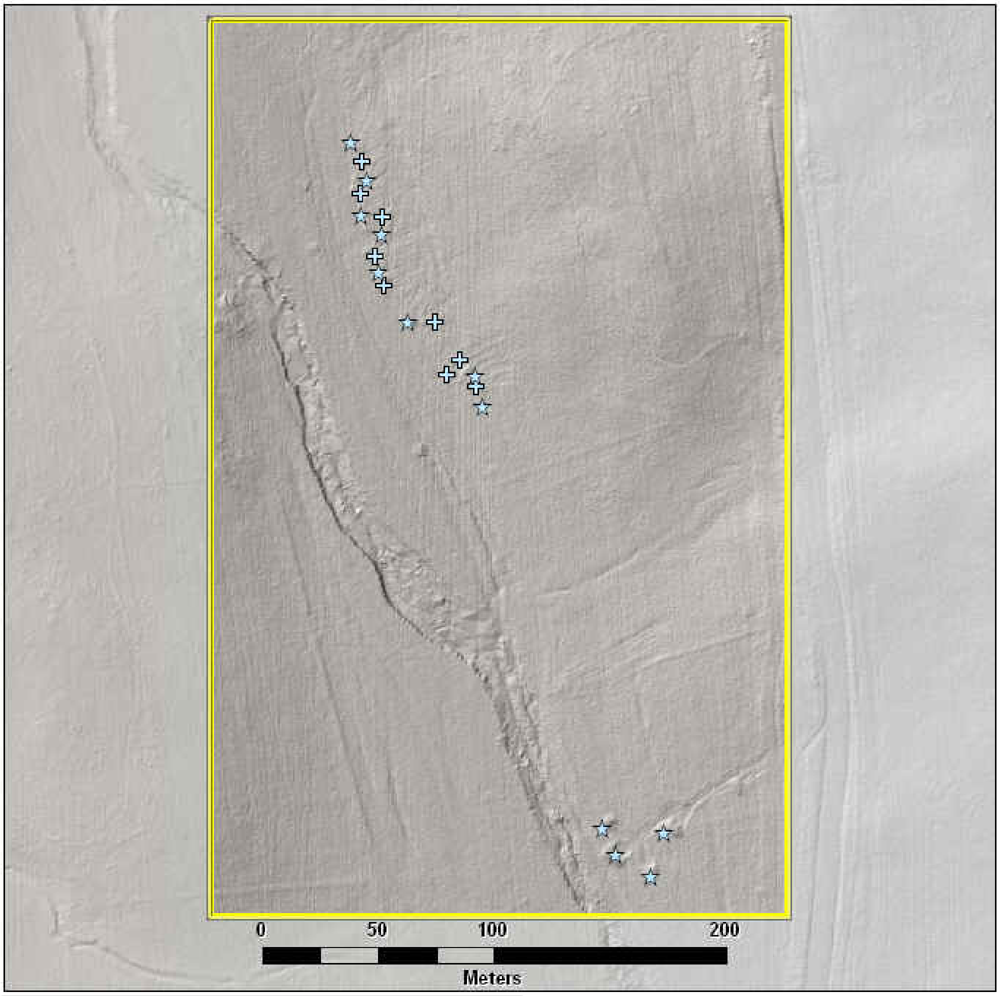
Figure 4-10.24 – Area of Interest 24

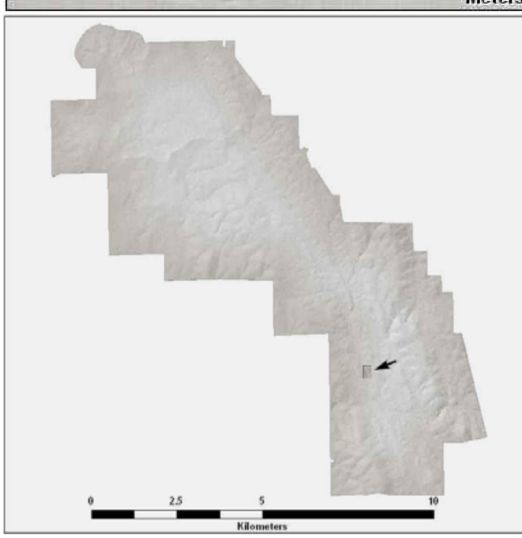




Area of Interest: 24
Original Classification: Potential MEC features
Original Classification based on: Potential craters arrayed along old road
CSM targets: No HE bombing targets
Field Visit: Not visited
Revised classification: Other features of interest
Revised classification based on: The clustering of the features appears more consistent with mining exploration.
Confidence level: Medium, no field visit. The area remains ambiguous and warrants further validation.

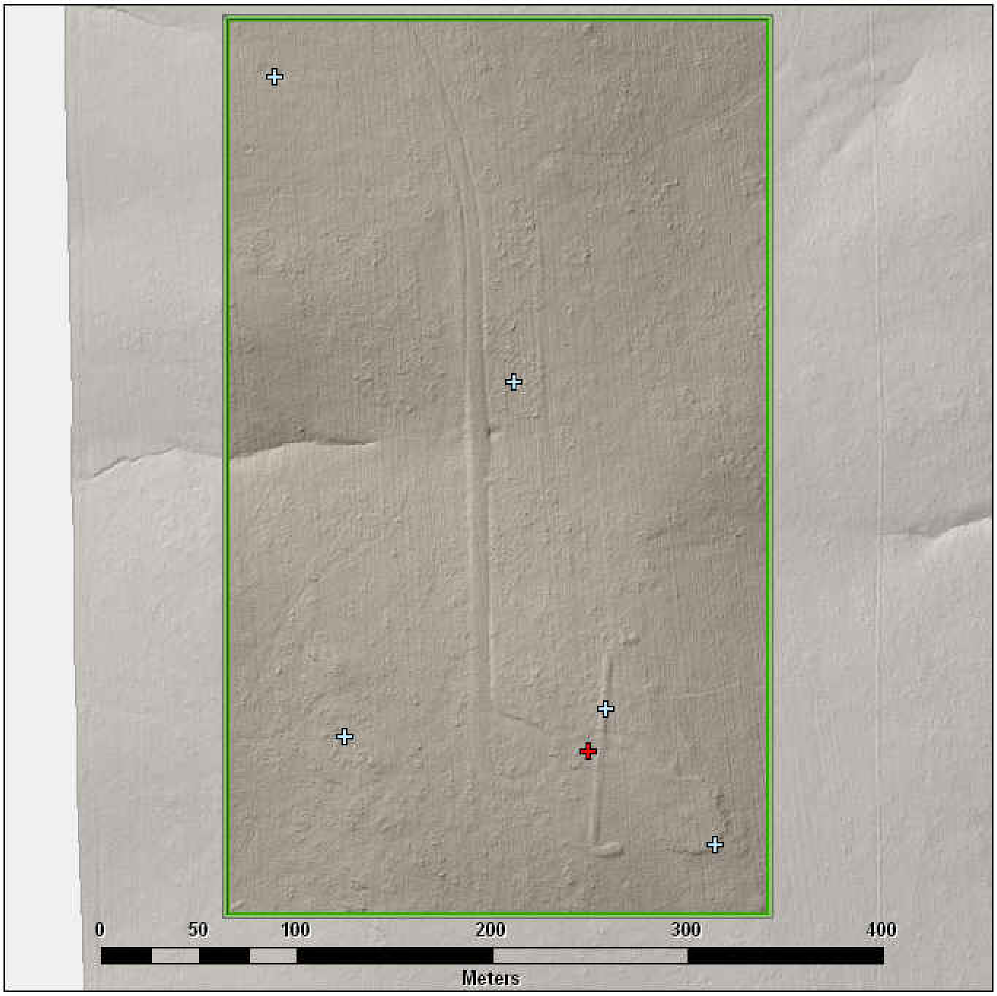
Figure 4-10.25 – Area of Interest 25

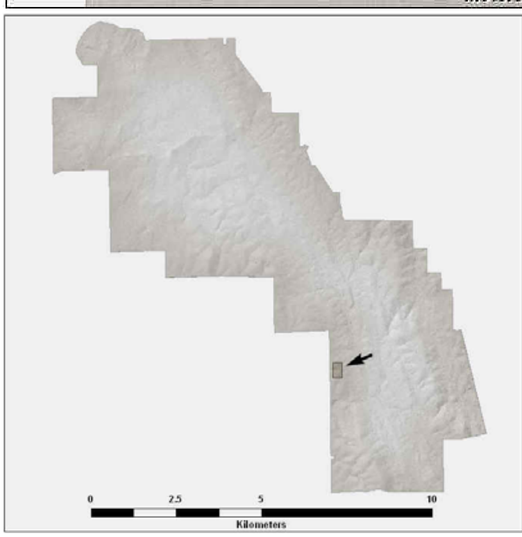




Area of Interest: 25
Original Classification: Potential MEC features
Original Classification based on: Regular pattern of berms
CSM targets: No HE bombing targets
Field Visit: Site was visited
Revised classification: Other features of interest
Revised classification based on: Negative mag response at all features visited. Visual inspection showed berms and ground disturbance more consistent with mining exploration.
Confidence level: High

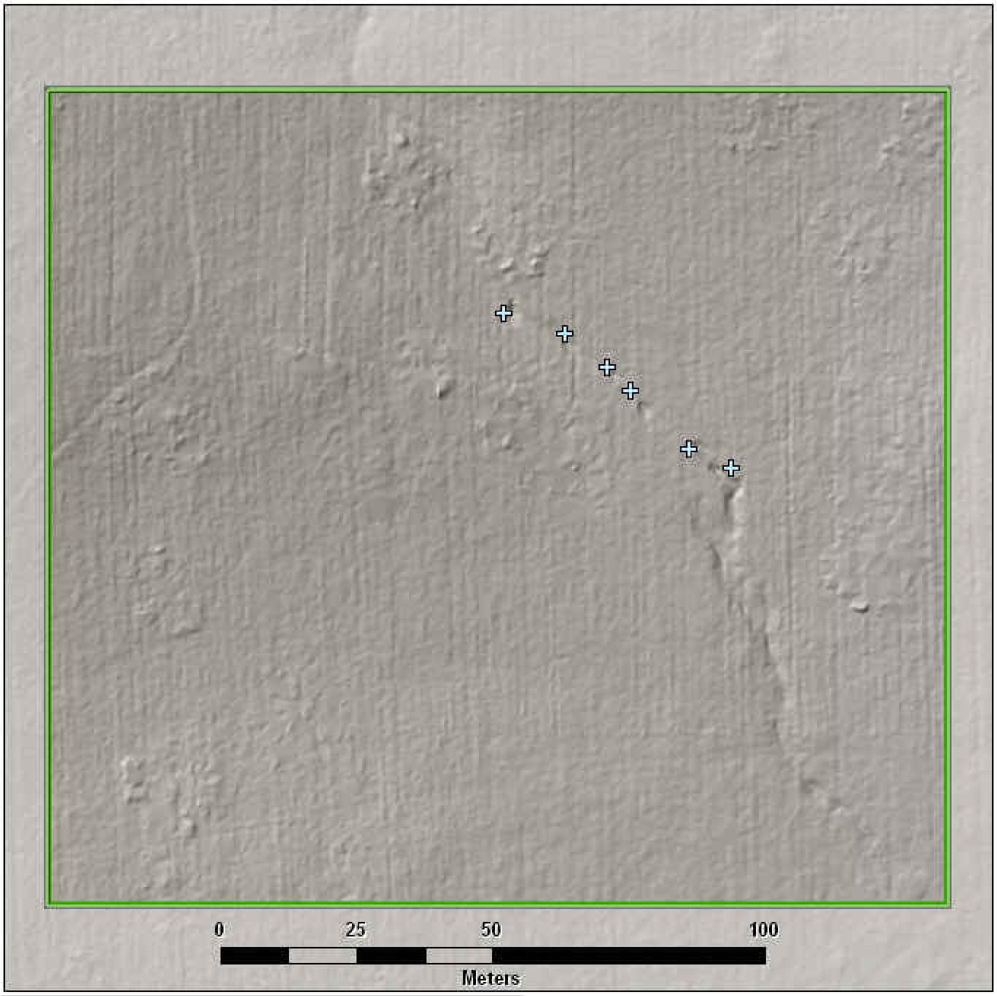
Figure 4-10.26 – Area of Interest 26

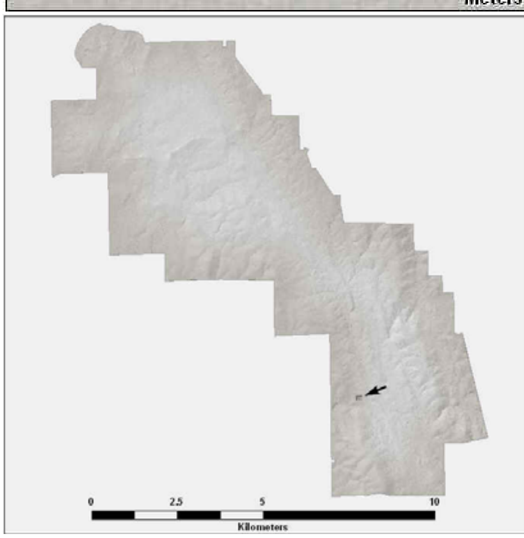




Area of Interest: 26
Original Classification: Other features of interest
Original Classification based on: Linear surface feature with scattered depressions
CSM targets:.30 Cal. Close Combat Range 11 (1959)
Field Visit: Not visited
Revised classification: Potential MEC Features
Revised classification based on: Depressions are scattered and most do not resemble ordnance use. One depression appears more likely to be ordnance-related based on its size and shape.
Confidence level: Medium - low, no field visit. Because UXO staff identified one potential MEC feature, the area remains ambiguous and warrants further validation.

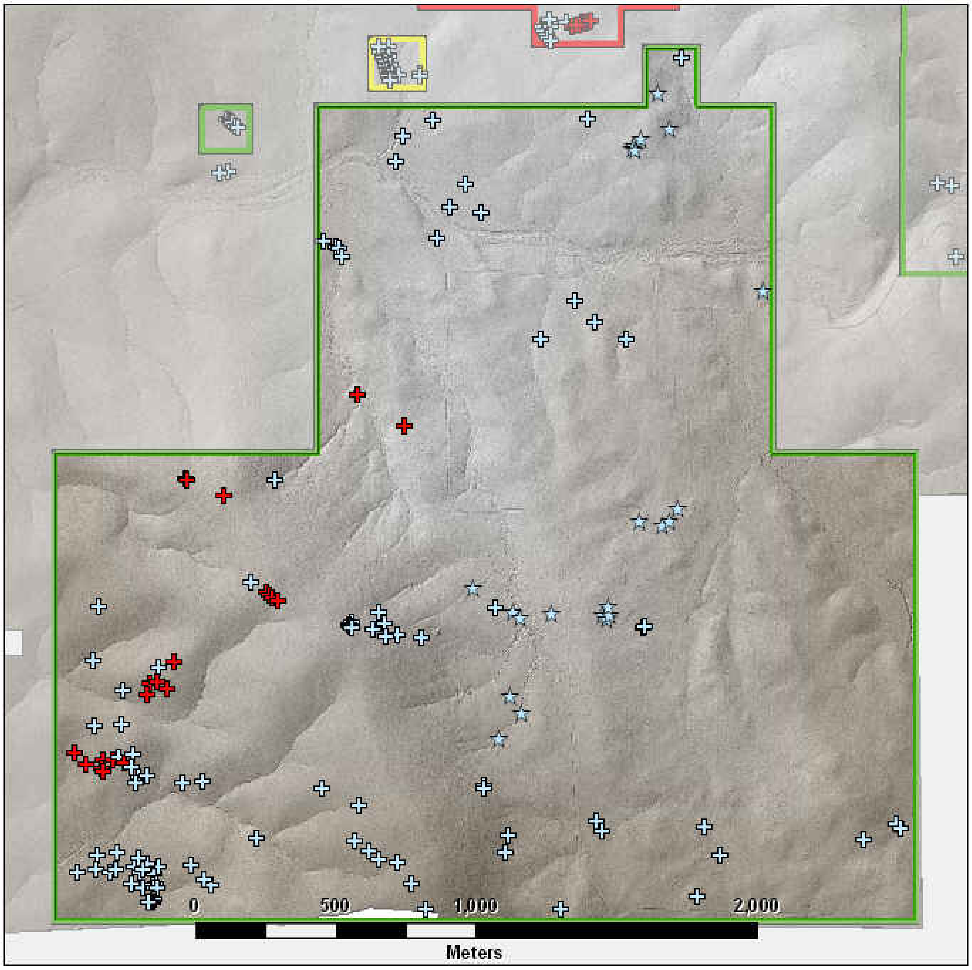
Figure 4-10.27 – Area of Interest 27

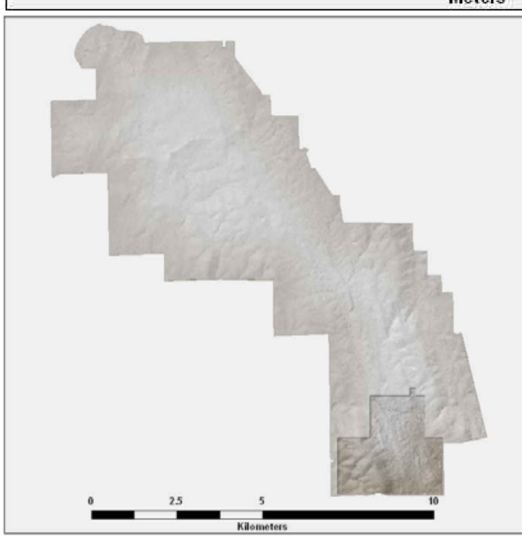




Area of Interest: 27
Original Classification: Other features of interest
Original Classification based on: Regular line of depressions in seasonal stream course
CSM targets: No HE bombing targets
Field Visit: Not visited
Revised classification: Other features of interest
Revised classification based on: Depressions are not clustered in a manner consistent with ordnance use, nor are they near obvious roads. There is no CSM correlation.
Confidence level: Medium, no field visit

Figure 4-10.28 – Area of Interest 28





Area of Interest: 28
Original Classification: Other features of interest
Original Classification based on: Scattered depressions
CSM targets: Target No. 2 (1956/9)
Field Visit: Part of site was visited
Revised classification: Potential MEC features
Revised classification based on: Negative mag response at all features visited. Most depressions had sizes and shapes that were not consistent with ordnance use. Some features not visited appeared probable MEC on subsequent review based on size and shape.
Confidence level: High (for the portions of the site visited, Medium (for the portions not visited). The portion of the site not visited remains ambiguous and warrants further validation.

4.3 DATA ANALYSIS, INTERPRETATION AND EVALUATION

4.3.1 General Observations

The Former Camp Beale site was a logical extension of the WAA Pilot Program to a more complex site. The site was more challenging in at least two dimensions. First, the area had been used for a wider variety of munitions-related activities than the previous sites, including not only bombing ranges but also firing and training ranges. Second, the site was used for a much wider variety of non-munitions-related activities, especially including mining exploration. As a result of both of these factors, the Former Camp Beale site presented a much wider range of potential features. Nevertheless, the overall objectives of the demonstration were met:

- Lidar and orthophotos were used to identify potential bombing targets and firing ranges with a high level of confidence.

- Lidar and orthophotos were used to correct what appeared to be an erroneous target location in the initial CSM.

- Lidar and orthophoto data were used to produce lists and locations of ambiguous features for further investigation.

- Lidar and orthophoto data provided information on topography and vegetation that was used to plan magnetometry and EMI transects.

The primary difference between the Former Camp Beale site and first phase sites was that at Former Camp Beale there were a larger number of features whose origins could not be determined using the lidar and orthophoto data alone. The history of mining exploration at the site was particularly problematic, since this activity produced depressions that could not easily be distinguished from potential craters. However, the origin of most or all of these features could be resolved with field investigation using hand-held magnetometry.

These results emphasize the appropriate use of lidar and orthophotos at the beginning of the site investigation process, and the importance of following the use of lidar and orthophotos with technologies such as magnetometry and EMI that directly detect ordnance components.

4.3.2 Correlations with Operating Parameters and Performance Specifications

For orthophotos, the demonstration verified that 10 cm pixel orthophotos performed better than the 30 cm pixel orthophotos already available. This finding is significant since 30 cm pixel orthophotos are the highest density images that are generally available to site managers.

For lidar, while higher lidar data density produced very detailed ground surface models, they did not perform notably better than the higher data densities collected at the Kirtland PBR or Victorville DBT "Y" sites in terms of actual feature detection. Test craters at 1.0 m and 1.5 m diameters were reliably detected, but even at the high data densities achieved, 0.30 m (1 ft.) diameter test craters could be missed.

Nevertheless, there are some reasons to acquire additional lidar density if the project budget and the vendor's equipment allow. Additional lidar density did help to define features more clearly, and work at the Kirtland PBR and Victorville DBT "Y" demonstration sites showed that lidar data density varies considerably over the project area, with individual small areas well above and below the target density. Increasing overall lidar density is one way to compensate for areas that are less dense than planned.

4.3.3 Optimum Operating Conditions and Appropriate Uses of the Technologies

The results from the Former Camp Beale site re-enforce the general premise of the WAA Pilot Program: lidar and orthophotos should be the first technologies to be deployed after completion of the ASR and the initial CSM. At all three sites examined, lidar and orthophotos were successful at revealing and verifying the broad picture of munitions use. Lidar, especially, was very successful at delineating targets and crater fields, as well as additional areas of interest that warranted investigation. The two technologies complimented each other well, each providing data that the other did not. Since vendors generally deploy these two technologies together, it makes sense to acquire both at future production sites.

The demonstration also supports the WAA Pilot Program assumption that lidar and orthophoto acquisition should be followed with technologies that directly detect ordnance components. This was especially true for the Former Camp Beale site, where so many features were ambiguous.

Table 4-2
Data Quality Metrics, Individual Performance Measures

	Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result	Actual Result
Pre-flight Activities						
1	Study area boundary delineation	Site boundary polygon characteristics agreed upon and documented to allow comparison with data collected.	Achieve stakeholder agreement to boundary parameters.	Once, start of program.	Document site boundary for measurement of future boundary metrics.	Accomplished. Boundaries were agreed upon and utilized.
2	Survey control point confirmation measurement	Confirm coordinates of survey control points within at least 3rd order accuracy.	Perform and record GPS survey (static or kinematic).	Pre-flight (or during on-site acquisition).	Confirm coordinates of survey control points.	Accomplished. Control points were independently occupied by TRSI and ESTCP.
Lidar Data Collection and Processing						
3	Sensor calibration	Resolve roll/pitch/ heading for installation.	Perform opposing direction and orthogonal passes over baseline. Compare with nominal values from standard installation.	Prior to each flight day.	+/– 0.02 degrees	Accomplished. Standard roll, pitch and heading correction factors were established through calibration flights for both sites. See Lidar Positional Accuracy Report, below.
4	Sensor speed	Laser pulse rate between 50-100 kHz.	Set laser pulse speed and the altitude of the low lidar passes depending on site conditions to achieve highest possible point density.	Prior to each flight day.	Achieve target sensor speed.	Accomplished. Laser pulse rate of 75 kHz was used at both sites.

5	Flight altitude, Victorville	Flight altitudes of 450 and 300 m.	Establish and fly appropriate flight altitudes for the desired lidar point densities and orthophoto pixel sizes. Lay out a series of flight lines for high-density lidar collection to be able to respond to site conditions.	Each flight line.	+/- 50 m from planned flight altitudes.	Accomplished. Lidar flight altitudes were 450 and 300 m. Flight altitudes are documented through daily flight logs.
6	Area coverage	100% coverage for each flight.	Establish and fly flight lines so as to cover the entire target area. Data from each day's flights will be examined and data gaps will be filled.	Each flight	100% coverage.	Accomplished. 100% coverage of the study area was accomplished for each flight at both sites.
					15% flightline overlap, 50m over area boundaries.	Accomplished. Flight line overlap met specifications for all flights.
7	Data collection rate	Collect data for the entire site within the established schedule. Reserve one additional day for QA/QC and re-flights	Establish and review flight lines and flight schedule prior to data collection.	NA	Full data collection within planned schedule.	Partially Accomplished. Data collection at Camp Beale required two additional days due to high ambient air temperature.
8	Lidar point density	Achieve overall densities of: 5 pts/m^2 for the 300 m flight and 3 pts/m^2 for the 450 m flight	Plan and accomplish appropriate sensor speed, flight altitude, and air speed. Flights more than 10% below target point densities will be repeated.	Each flight.	Data collection within 10% of target densities.	Accomplished. Achieved data density for the 300 m flight was 13.8 pts/m^2 and 13.7 pts/m^2 for the 450 m flight.
9	Lidar flight line alignment	The 450 m and 300 m flights were not to exceed an intersection angle of 90°, +/- 10°.	Appropriate flight lines will be designed and flown. Planned flight lines will be submitted in advance.	Each flight	Flight lines within 10^o of orthogonal.	Accomplished. No computed intersection angle exceeded the tolerance criteria of 90°, +/- 10°.
10	Lidar vertical accuracy	Vertical accuracy of +/– 15 cm compared to	Steps:	Each flight		

		ground survey.				
			1. Perform sensor calibration as described above		As above	Accomplished.
			2. Obtain ground elevations on identifiable points using ground based GPS methods (static and/or kinematic)		As above	Accomplished. Control points were collected as described.
			3. Compare ground-based and airborne elevations.		Meet or exceed +/1 15 cm lidar to control point vertical accuracy.	Accomplished. Elevation comparisons were performed between control point elevations and the interpolated elevation of the Lidar surface at that point. Results were within specifications. See Positional Accuracy Report.
11	Lidar horizontal accuracy	Both Sites: Horizontal accuracy of +/– 65 cm compared to ground survey	Steps:	Each flight		Accomplished. Positions of control points were obtained in the Lidar data using intensity values. These positions were compared to the surveyed locations of these control points. Horizontal accuracy was well within specification. See Lidar Positional Accuracy Report.
			1. Perform sensor calibration as described above		As above	Accomplished.
			2. Obtain ground positions on identifiable points using ground based GPS methods (static and/or kinematic)		As above	Accomplished.
			3. Compare ground-based and airborne positions.		Meet or exceed +/- 65 cm lidar to control point horizontal accuracy.	Accomplished.

12	Lidar data integration – flight lines	Both Sites: Achieve flight line to flight line edge match of +/– 12cm.	Review statistics from lidar processing software.	Line to line	Achieve best possible match between individual lidar flight lines.	Accomplished.
13	Lidar point separation	Both Sites: Remove 100% of large features, (trees, buildings, vehicles)	Operators remove non-ground laser returns through automated separation routines followed by hand cleaning and inspection.	Lidar data set for each flight	Satisfactory visual inspection of surface model of the ground surface.	Accomplished. Lidar points were classified as ground and non-ground returns. Visual inspection of the ground returns showed that all trees, buildings, fences, and other larger features were successfully removed.
		Remove small features (grass, low brush) to the level where remaining data cannot distinguish ground from non-ground features.			Satisfactory visual inspection of surface model of the ground surface.	Accomplished. Inspection of ground and non-ground Lidar points in conjunction with orthophotos showed that small brush and tall grass was removed within specification.
Orthophoto Data Collection and Processing						
14	Orthophoto area coverage	Both Sites: 100% coverage for each flight.	Wireframes of "raw" images are compared to the project boundary to check for gaps or holes.	Each flight day as part of QA/QC checks.	100% coverage with sufficient image overlap for ortho-rectification.	Accomplished.
15	Orthophoto flight altitude/ pixel size	450 m (for 10 cm pixel flight)	Orthophoto pixel size is directly related to flight altitude. Flight lines are designed for the desired pixel sizes. Flight data will be examined during and after each flight and flight lines outside of the range will be repeated.	Each flight	Achieve specified flight altitudes and pixel sizes.	Accomplished. 10 cm pixel sizes were achieved for 100% of the study area.
16	Orthophoto image	No obvious seams between images in the	Creation of an image mosaic from individual small images is	Each orthophoto	Line features are continuous with	Accomplished. Visual inspection of the orthophoto images showed no

	mosaicing	final orthophoto.	largely an operator controlled rather than an automated process.	composite image	no visible discontinuity at mosaic seams.	obvious seams.
17	Orthophoto image color balancing	No obvious color imbalances within data for each session.	Color balancing is an operator controlled process based on viewing the mosaic to identify any areas of tonal imbalance.	Each orthophoto composite image	Continuity of tone such that individual images are not visible in mosaic.	Accomplished. Visual inspection of the orthophoto images showed no obvious color imbalances.
18	Orthophoto horizontal alignment to lidar	Lidar and orthophotos aligned so that target features are not displaced in the two data sets.	Orthorectification is performed using the lidar data and fiducial locations are control data sources, followed by operator adjustment.	Each orthophoto composite image.	Orthophotos aligned to +/– 2 pixel widths.	Accomplished. Positions of control targets were compared using the orthophoto and lidar intensity values. Locations were within specifications.
19	Orthophoto horizontal alignment to fiducials	Both Sites: Orthophotos aligned to survey control points so that target features are not displaced.	Orthorectification is performed using the lidar data and fiducial locations are control data sources, followed by operator adjustment.	Each orthophoto composite image.	Orthophotos aligned to +/– 3 pixel widths.	Accomplished. Ortho image positions were compared to control targets visible in the images. In addition, lidar and orthophoto positions were compared for building corners and edges of pavement that were visible in both the orthophoto and lidar data. Positions were within specifications.

Table 4-3
Data Quality Metrics, MRS Identification and Analysis

MRS Identification and Analysis						
20	MRS identification	Correctly identify all previously identified MRS.	Identify and document MRS from lidar and orthophoto data sets.	Each lidar and orthophoto data set and combinations.	Correctly identify all MRS.	N/A. The initial CSM gave target areas but not specific MRS. Lidar and orthophotoss did locate one MRS outside of the mapped target areas.
21	MRS false alarm rate	No areas incorrectly identified as MRS.	Identify and document MRS from lidar and orthophoto data sets.	Each lidar and orthophoto data set and combinations.	No false MRS identification.	Not Yet Determined. The initial areas of interest included some areas of “potential MEC related features” that were tentatively identified as not munitions related. Many features remain ambiguous.
22	MRS boundary delineation	Correctly locate MRS boundaries to +/– 15% of ground-truthed area.	Identify and document MRS boundaries from lidar and orthophoto data sets for a selected set of test MRS.	Each lidar and orthophoto data set and combinations.	Locate MRS boundaries within metrics.	Not Yet Determined. Five MRS were tentatively identified. Field verification of MRS boundaries has not yet been completed.
23	MRS feature identification	Identify features presenting as human-made (anthropogenic) not including craters (e.g., walls, berms, pits, small buildings).	Lidar and photo data sets will be examined for linear features.	Each lidar and orthophoto data set and combinations.	90% of features identified from selected field-identified features.	Accomplished. Potential human-made features were readily identifiable.

Data management						
24	Data management	Data backup and storage to achieve redundancy and security.	Data will be backed up to separate redundant hard drives or tape drives.	Daily backup during field and data processing operations.	Data security, prevention of data loss.	Accomplished. All data was and remains backed up to redundant hard drives.
25	Data collection report	Standard flight reporting includes: calibration log,	The data collection report is a standard QA/QC product.	Calibration report: each flight day.	Full reporting is a required part of contract performance.	Accomplished. Calibration flights were accomplished and standard pitch, roll and heading adjustment values were calculated and recorded.
		Flight log, QA/QC log, and site photos.		Flight log: each flight.	Full reporting.	Accomplished. Flight log data was recorded and delivered.
				QA/QC log: each flight.	Full reporting.	Accomplished. Flight logs and QA/QC report were provided.
				Site photos: whole project.	Full reporting.	Accomplished. Site photos were taken and delivered.
26	Data processing report	Standard data processing report includes: GPS control ties, accuracy verification report, and QA/QC report.	The data processing report is a standard QA/QC product.	Each lidar and orthophoto data set.	Full reporting is a required part of contract performance.	Accomplished. GPS control, accuracy verification report and QA/QC reports were delivered.
27	Metadata	Metadata to accurately describe data format and processing steps.	Data will meet US Government SDS and fully comply with Versar EDD specifications including metadata standards.	Each data transfer.	Metadata meets required standards.	Accomplished. ESTCP staff stated that SDS standards would not apply but that metadata would be required. Standard GIS metadata files were delivered with all data.
28	QA/QC	All data and derived products will be subject to appropriate QA/QC review.	Data processing will follow the QA/QC plan described herein.	Each data transfer.	Data are valid useful for the intended purpose and defensible.	Accomplished. Each data deliverable was independently reviewed by the GIS Lead and a standard QA/QC form filled out

						and placed in the project files.
29	Data delivery	All data will be delivered in a timely and easy-to-transfer manner.	Data deliverables will be made using ftp where possible, but in all cases will be followed up with delivery on physical media, primarily external hard drives.	Each data transfer.	Meeting data deliverable deadlines.	Accomplished. Data was delivered on or before the dates given in the Demonstration Plan. Interim data deliveries were made by DVD or external hard drive. Final data delivery was accomplished through external hard drive.

5.0 COST ASSESSMENT

5.1 COST REPORTING

Table 5-1 presents actual costs for the Kirtland, Victorville and Former Camp Beale demonstration sites, and estimated costs for production sites of two additional sizes. The figures for the two production sites are planning-level estimates, assessed to be accurate within +/- 20%. Per acre costs for the Kirtland site were higher since four rather than two lidar flights were conducted, and one rather than two orthophoto sets were created. The Victorville configuration, with one lidar/orthophoto flight and one additional lidar-only flight, is considered representative for a production site where it is important to detect both targets and individual small features and was used at the Camp Beale site. The "50,000 acre production site" estimate is based on URS' previous experience and interviews with industry sources, and the "115,000 acre production site" estimate is based on a cost proposal made by URS for a site in the western US in Fall, 2005. All figures are in 2006 US dollars and costs were updated in June 2007. All projects listed can be completed in less than one year; therefore no discount factor has been applied to the figures.

Table 5-1
Actual and Projected Costs

Project Parameters	Kirtland	Victorville	Former Camp Beale	50,000 acre Production Site	115,000 acre Production Site
Project area size (acres)	5,000	5,640	18,000	50,000	115,000
Project area size (hectares)	1,914	2,282	7,284	19,140	44,022
Lidar flights:					
300 m (Lidar only)	2	1	1	1	1
450 m (Lidar and 10 cm pixel imagery)	1	1	1	1	1
900 m (Lidar and 20 cm pixel imagery)	1	0	0	0	0
Total Lidar flights	4	2	2	2	2
Total Lidar point density (pts/m2)	20	8-10	8-10	8-10	8-10
Orthophoto pixel size (cm)	10 and 20	10	10	10	10
Costs:					
Fixed Costs					
Mob/demob	15,600	23,100	21,800	30,000	45,000
Planning/preparation	15,000	9,200	15,000	15,000	20,000
Project management	15,000	10,000	25,000	40,000	100,000
Site work	0	0	0	0	0
Equipment cost	0	0	0	0	0
Start-up and testing	0	0	0	0	0
Subtotal fixed costs	45,600	42,300	61,800	85,000	165,000

Table 5-1 (Continued)
Actual and Projected Costs

Project Parameters	Kirtland	Victorville	Former Camp Beale	50,000 acre Production Site	115,000 acre Production Site
Variable Costs					
Data acquisition	39,900	34,100	85,300	160,000	355,000
Data processing	45,800	35,200	102,900	250,000	575,000
Data analysis and GIS products	94,300	30,000	68,100	150,000	220,000
Data reporting and documentation	13,600	8,500	12,000	15,000	25,000
Materials and consumables	1,500	1,000	1,500	5,000	10,000
Other Direct Costs	**0**	**0**	**0**	**0**	**0**
Subtotal variable costs	**195,100**	**108,800**	**269,800**	**580,000**	**1,185,000**
Total project cost	**240,700**	**151,100**	**331,679**	**665,000**	**1,350,000**
Total per/acre cost	**48.1**	**26.8**	**18.43**	**13.3**	**11.7**
Total per/hectare cost	**125.8**	**66.2**	**45.53**	**34.7**	**30.7**

5.2 COST ANALYSIS

5.2.1 Cost drivers

The major cost drivers for the Camp Beale site largely confirmed the findings from the Kirtland and Victorville sites. These were:

- Lidar data density required. For the Kirtland site, four lidar flights were conducted; two concurrently with digital imagery collection, and two lidar-only flights. For the Victorville site, one lidar/orthophoto flight and one lidar-only flight were conducted. For Camp Beale, two lidar flights were conducted.

- Orthophoto data density required. For the Kirtland site, two sets of digital images were collected, and orthophotos were created at 10 cm and 20 cm pixel sizes. For the Victorville site, only 10 cm pixel size was collected. For the Victorville and Former Camp Beale sites, only10 cm pixel orthophotos were acquired.

- Accuracy and precision requirements. A higher level of survey control was needed at the Camp Beale site than for production sites, including collecting 16 control points, 10 test craters and 4 vertical control structures. For production projects, fewer survey control points and vertical control structures would likely be needed. However, the cost of project control is small relative to that of data acquisition and processing, and the cost savings would be relatively minor.

- Site location and logistics. The Camp Beale site location affected project costs both positively and negatively. The site is situated close enough to the Yuba Airport so as to not require establishing a fuel cache on site or to require the aircraft to land. Negative factors included the proximity of the PAWS radar installation which interfered with the lidar equipment requiring additional data processing and the excessive ambient temperatures experienced during the data acquisition flights which limited the flights to the early morning hours and required slower aircraft speeds.

In addition to the cost drivers listed above, costs for production sites will be affected by the following additional factors:

- Site size. Larger sites achieve cost savings through amortization of fixed costs such as mobilization and project planning, as well as through increased efficiency in data acquisition and processing. This effect can be seen in Table 5-1

- Vegetation conditions. Highly vegetated sites may have higher costs due to the requirement for additional lidar passes to achieve sufficient density of points reaching the ground surface. Alternatively, it may be possible to achieve sufficient vegetation penetration by specifying the use of higher speed sensor equipment.

- Permitting and site access constraints. DoD sites with sensitive, high-security areas may have higher costs. However, such conditions would typically affect only pre-flight planning and equipment mobilization costs rather than data acquisition, processing and analysis costs. Sites with environmental constraints do not normally impose significantly higher costs for lidar and orthophotography since the airborne nature of the technologies does not typically affect sensitive species or environments.

5.2.2 Cost Sensitivities and Additional Potential Savings

Additional savings could be realized through either of the following methods:

- Acquiring orthophotography with a larger pixel size. The cost of acquiring and processing orthophotography rises dramatically for smaller pixel sizes, and acquiring orthophotos at 20 cm pixel size rather than 10 cm would reduce the data acquisition and processing costs by 30 – 35%. The utility of such photos would be lower since their resolution will not allow discrimination of smaller features.

- At highly vegetated sites, orthophotos are inherently less useful, and orthophotos with larger pixel sizes may be acceptable or orthophoto collection may be eliminated altogether if pre-existing orthophotography is available and its positional accuracy can be verified. However, at relatively open-sky sites, site managers should consider acquiring 10 cm pixel orthophotos. Experience during both phases of the WAA Pilot

Program has shown that these are significantly more useful than orthophotos with larger pixel sizes.

Acquiring lower-density lidar data. Eliminating the assumed second lidar flight, and thus only collecting lidar with the 10 cm orthophoto imagery, would reduce costs by 25 to 30%. The ability of the resulting lidar data set to discriminate features would be reduced, however this might be appropriate if the lidar data was to be used only to discriminate large features such as bombing targets or roads, rather than smaller features such as craters. Alternatively, DoD could specify use of a faster lidar sensor, which could meet lidar data density requirements from a single pass.

Some additional cost savings could potentially be achieved by establishing Service- or DoD-wide standards for data acquisition, GIS data product creation, data delivery formats, and project reporting.

5.3 COST COMPARISON

Cost comparisons with the other innovative technologies demonstrated as part of the ESTCP WAA Pilot Program will be made in the Final Report for the WAA Pilot Program.

6.0 IMPLEMENTATION ISSUES

6.1 ENVIRONMENTAL CHECKLIST

No environmental regulations applied to the demonstration and no permits were required.

6.2 OTHER REGULATORY ISSUES

Both lidar and orthophotography are in wide commercial use. Within the United States, no regulatory restrictions are known that would impede the wide use of either technology at DoD sites. Outside of the United States, use of advanced IMU equipment may be restricted in certain countries. The IMU used in lidar systems is military dual use technology and international use requires a permit under the International Traffic in Arms Regulations (22 CFR 120-130). Additionally, some countries impose a variety of restrictions on the acquisition, processing and subsequent use of lidar and orthophoto data collected within their borders, particularly in border or military-use areas. Potential users of lidar in such situations should investigate such restrictions as part of project planning.

6.3 END-USER ISSUES

Both lidar and orthophotos are in wide commercial use and do not face substantial end-user issues.

7.0 REFERENCES

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